2005

Vibrotactile Guidance Cues For Target Identification

Joshua Downs
University of Central Florida

VIBROTACTILE GUIDANCE CUES FOR TARGET IDENTIFICATION

by

JOSHUA LEE DOWNS
M.S. Florida Institute of Technology, 1998

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Psychology
in the College of Arts and Sciences
at the University of Central Florida
Orlando, Florida

Spring Term
2005

Major Professor: Richard D. Gilson

ABSTRACT

The purpose of this dissertation was to establish how vibrotactile guidance cues can be used to improve marksmanship. This work originated in an effort to provide covert communication, navigation, and weapon aiming cues for infantrymen. It is predominantly an application-driven investigation rather than driven a priori by specific theoretical predictions from models of human performance. Three experiments are presented. Experiment 1 established the affect on initial response to vibrotactile guidance cues of tactor placements on the palmer versus dorsal surface of the hand, and targets appearing left versus right of center. Results suggest that tactile cues provided on the left side of the medial line of the hand afford moving the hand to the left, while tactile cues provided on the right side of the medial line afford moving the hand to the right. Experiment 2 established the affect of continuous relative distance cues and on- versus off-target vibrotactile stimuli on reaction time and accuracy for target selection. Results indicated an interaction between the pulse rate of vibrotactile stimuli and the method used to highlight an "on-target" condition; the suppressed target condition was superior to the enhanced target condition when the pulse rate increased as the cursor moved closer to a target. Experiment 3 established if there are performance differences between discrete and continuous distance information for target selection, and investigated the interaction between the near-target pulse rate and on-target cues. Results indicate that maximizing the difference between near-target guidance cues and on-target cues reduces the target selection time, particularly when the near-target pulse rates are fast (ISI = 10 msec). The results also suggest that, as with vision, the vibrotactile off-target guidance cues are not necessary during the whole

target selection task. Rather, the guidance cues can be provided only during the initial pop-up condition and during the sub-movements closing on the target.

For my wife and best friend, 김 경은.

ACKNOWLEDGMENTS

I would first like to thank Stanley Roscoe for the inspiration of his book “Aviation Psychology”. Without this book I might never have known I could make a living by my passion for interface design. Without his book I might not have been able to put my dad’s fears so quickly to rest when I had phoned home about this hybrid field of study he had never heard of.

Next, I would like to thank my mentor Richard D. Gilson. You introduced me to the wonderful woman who would become my wife. You guided me through the flaming hoops and hurdles of a Ph.D. degree, and had to put up with my mental meanderings during the long process of developing my dissertation.

I should also thank NAWC-TSD, Honeywell Laboratories, and DARPA for their support. I couldn’t have made it through the program without the experiences and the resources that they provided.

Special thanks go out to my wife, who did all the cooking and (most…) of the dishes while I was sweating the deadlines for this project. 여보, 고맙습니다!

Finally, for their undauntable patience and tolerance, I thank my committee chair, Richard D. Gilson, committee members Peter A. Hancock and Edward J. Rinalducci, and my non-departmental committee member Tal Oron-Gilad. Special thanks to Tal Oron-Gilad, whose tireless guidance and persistence helped to steer my course to completion of this project.

Murphy was an optimist.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

EHI	Edinburgh Handedness Inventory
GLM	General Linear Model
GraC	Pulse Rate Gradient Continuous
GraCDi	Pulse Rate Gradient Continuous or Discrete
GraD	Pulse Rate Gradient Down
GraDi	Pulse Rate Gradient Discrete
GraDo	Pulse Rate Gradient Down
GraU	Pulse Rate Gradient Up
GraUD	Pulse Rate Gradient Up or Down
GraUDo	Pulse Rate Gradient Up or Down
iMT	Initial Movement Time
iMove	Probability of Correct Initial Movement
ISI	Inter Stimulus Interval
LARS	Laser Aiming Reference System
LSD	Tukey's Least Significant Difference
msec	Millisecond
nClicks	Number of Mouse Clicks
otCnt	On-Target Count
SME	Subject Matter Expert
ST	Target Selection Time
TacD	Tactors Dorsal

TacP	Tactors Palmer
TacPD	Tactors Palmer or Dorsal
TAGS	Tactile Aiming Guidance System
TarE	Target Enhanced
TarEf	Target Enhanced Fast Pulse Rate
TarEs	Target Enhanced Slow Pulse Rate
TarL	Target Left
TarLR	Target Left or Right
TarR	Target Right
TarS	Target Suppressed
TarSE	Target Suppressed or Enhanced
TarSEsf	Target Suppressed or Enhanced Slow or Fast
TDB	Tactor Discriminability Bias
WY-Feel-IWYG	What You Feel Is What You Get
WYSIWYG	What You See Is What You Get

CHAPTER ONE: BACKGROUND

The purpose of this dissertation was to establish how vibrotactile guidance cues can be used to improve marksmanship. This work originated in an effort to provide covert communication, navigation, and weapon aiming cues for infantrymen. It is predominantly an application-driven investigation rather than driven a priori by specific theoretical predictions from models of human performance.

Though this project was motivated by an application focusing on marksmanship, other applications are readily apparent; any application requiring the tracking or selection of a target condition may benefit from this research. Angioplasty surgery and intravascular coronary ultrasound, way finding in a visually demanding environment such as in a city, and rambunctious object tracking (i.e., keeping track of small children) are examples. In all of these examples it is necessary to have real-time direction and distance information to achieve some desired target condition.

For this project, however, we focus on marksmanship.

Marksmanship

Typically, marksmanship requires a precise alignment of visual cues. When the sight picture is changing due to relative movement between the target and the weapon, the aim-point must be adjusted to account for this movement. This adjustment of the aim-point is a complex task often requiring a great deal of practice to achieve mastery. Once mastery is achieved, however, rapid and accurate aim-point alignment on target becomes routine and likely transferable to other weapons of the same class (e.g., pistols, assault rifles, sniper rifles).

Schmidt’s (1975) schema theory of motor learning and Schmidt, Zelaznik, Hawkins, Frank, and Quinn’s (1979) theory of motor-output variability provide a flexible and relatively complete picture of what may be happening during the target selection task. Through practice, generalized motor programs become available that allow for rapid, adaptable movements. Once triggered, the generalized motor programs allow for the use of feedback to modify the efferent signals in a movement. Since the marksman is normally able see his or her target relative to the aim-point, any deviation in actual aim-point off the desired aim-point provides feedback for moving the actual aim-point onto the desired aim-point.

An enhancement to the traditional iron sights, reflex sights and laser aiming reference systems (LARS) provide rapid and accurate WYSIWYG visual reference for aim-point adjustment. Reflex sites use an optical system that permits the marksman to align a single dot or crosshair with the target. LARS project a beam of coherent light directly onto the weapon’s aim-point, providing visual feedback reflected directly from the aim-point that can be used by the marksman to align the aim-point with the target. By removing the necessity to align a set of iron sights, Reflex sights and LARS reduce the complexity of the aiming task, potentially permitting faster alignment of the aim-point with the target. However, the LARS dot--and often the beam itself--can be detected by enemy combatants and traced back to its source. Relatedly, enhanced visual sights can be degraded by fog, smoke, dust, sand, and other obstructions.

<u>Tactile Aiming Guidance System</u>

Vibrotactile stimulation can provide spatially stabilizing cues for feedback of subtle changes in position (Priplata, Niemi, Salen, Harry, Lipsitz, & Collins, 2002; Akamatsu &

MacKenzie, 1996; Akamatsu & Sato, 1994; Minsky, Ming, Steele, Brooks, & Behensky, 1990). Once such a feedback system is engaged, any deviation from the point of origin can result in tactile stimulation indicating the direction and magnitude of the change in position. Likewise, spatial deviations from a desired position displayed tactually can provide robust position guidance and stabilization sufficient to improve the acquisition time and accuracy of fine cursor control (Jagacinski, Flach, & Gilson, 1983; Jagacinski, Miller, & Gilson, 1979).

Tactile aiming guidance systems (TAGS) may provide covert WY-Feel-IWYG aim-point adjustment that is as rapid and accurate as enhanced visual sights for aim-point adjustment. TAGS may also provide tactile feedback that can be used by the marksman to stabilize weapon aiming.

Since TAGS apply their stimuli to the hands or arms directly, and since TAGS are a tactile channel that may be capable of cooperating with the visual channel without interference (Wickens, 2002), their stimuli may have greater affordances for aim-point guidance and stabilization than the iron and enhanced visual sights. These affordances may translate into decreases in time to hit the target and decreases in number of bullets fired relative to visual aiming cues alone.

Research Questions Addressed Herein

Given the potential for TAGS to provide guidance cues for target selection, some developmental issues include:

1. Where should the tactors be placed?
2. Do the affordances change with tactor placement?

3. What kinds of stimuli should TAGS employ to give relative distance between aim-point and desired aim-point?

Experiment 1 was designed to address issues 1 and 2. Experiments 2 and 3 were designed to address issue 3. The affect of tactor placement on the affordance of vibrotactile stimuli applied to the hand was investigated in Experiment 1. The affect of continuous relative distance cues and on- versus off-target tactile stimuli on reaction time and accuracy were explored in Experiments 2 and 3. Experiments 1 and 2 revealed a consistent superiority of the visual and visual + tactile conditions over tactile-only. Both of these experiments provided evidence that vision is the dominant source of information for the object selection task employed. As such, only the visual + tactile and tactile-only conditions were employed in Experiment 3.

Experiments 1 and 2 provided evidence suggesting that the perceived left-ness and right-ness of the tactors is independent of which surface the tactors are located when the tactors are located on the same surface (i.e., palmer or dorsal). As such, the tactor placement in Experiment 3 was selected for ease of application, surety of placement, and sensitivity to vibrotactile stimuli.

Experiment 2 also provided evidence suggesting that continuous distance cues may interact with on-target cues when those cues use the same basic stimuli. As such, Experiment 3 further investigated the interaction between gradient of distance cues and the on-target cues examined in Experiment 2. Also, given that research has suggested that the visual display is not necessary for the entire duration of the movement of a fast target-selection task (Jeannerod & Prablanc, 1983; Carlton, 1981), Experiment 3 investigated both continuous and discrete vibrotactile distance cues.

Experiment 3 established the cueing effectiveness of vibrotactile guidance cues on the hand by employing the Fitts movement-time paradigm (Fitts, 1954; Fitts & Peterson, 1964; Fitts & Radford, 1966; Jagacinski, Pepperger, Moran, Ward, & Glass, 1980). Specifically, this study investigated discrete versus continuous vibrotactile relative distance cues, and on- versus off-target vibrotactile stimuli.

CHAPTER TWO: EXPERIMENT 1

Experiment 1 established the affect on initial response to vibrotactile guidance cues of tactor placements on the palm (palmer) versus on the back of the hand (dorsal), and targets appearing left versus right of center. It was expected that vibrotactile direction cues applied medially to the same surface of the hand will result in world-centric left-ness and right-ness independent of surface applied.

Design

The intent for Experiment 1 was to investigate the affect on affordance of tactile guidance cues of tactor placements on the palm (palmer) versus on the back of the hand (dorsal), and targets appearing left versus right of center. As such, Experiment 1 employed a two-way repeated measures design (see Table 1).

Table 1: Outline of the design for Experiment 1

	Target Left		Target Right	
	Palmer	Dorsal	Palmer	Dorsal
Tactile Only				

The within-subjects variables included Tactors Palmer or Dorsal (TacPD) and Target Left or Right (TarLR). Tactors Palmer refers to the tactors being placed between the mouse and the participant's hand (see Figure 1). Tactors Dorsal refers to the participant's hand being place between the mouse and the tactors (see Figure 2). These positions were chosen because they offered a mirror-image from palmar to dorsal surfaces that minimally interfered with the manipulation of the mouse. Target Left refers to targets to the left of center at the start of a trial. Likewise, Target Right refers to targets to the right of center at the start of a trial.

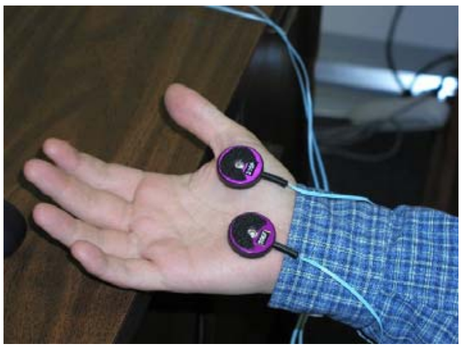


Figure 1: Palmer location of tactors

Figure 2: Dorsal location of tactors

Participants

24 undergraduate students at the University of Central Florida participated in this first Experiment. There were 12 males and 12 females in the sample. Though 3 males and 1 female stated that they write with their left hand, all participants stated that they use their right hand for mouse operations.

Apparatus

The software supporting this effort ran on a 3.00 GHz Dell Dimension 8300 with the Windows XP Professional operating system. Screen and color resolution was fixed at 1024 x 768 and 32-bit, respectively. A Dell M992 18 inch monitor was used to project the visual display. A Gyration Ultra inertial mouse was plugged into the high-speed USB port on the computer and functioned like a conventional three-button mouse with a scrolling wheel. The vibrotactile tactor system included two EAI C2 tactors, a tactor driver, and a Velcro strap for positioning the tactors. The computer sends commands and a 250 Hz sinusoid signal to the tactor driver, which in turn drives the tactors (see Figure 3).

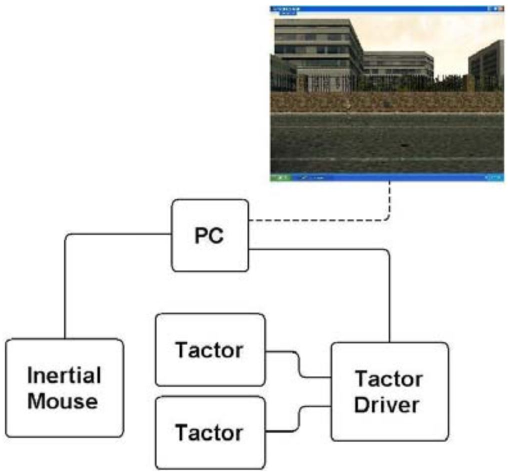


Figure 3: Block diagram of the system

In keeping with the Fitts movement-time paradigm, the software presented 2 sizes of targets (small and large) at 4 horizontal locations (2 left of center, and 2 right of center). The small targets were 14 pixels wide; large targets were 28 pixels wide. The center of mass of the target positions were located 423 pixels from the center of the display for the farthest targets, and 169 pixels from the center of the display for the closest targets. The order of presentation of the 8 targets was partially counterbalanced using the Latin Square technique for each participant.

Trials always started with the cursor at the center of the display. The cursor was constrained by the software to move only in the horizontal plane passing through the center of the screen and the center of mass of all targets. The inertial mouse was held unsupported in such a way as to align the forearm parallel to the floor. When the mouse is used in its inertial mouse mode, the user's hand naturally orients perpendicular with respect to the floor (see Figure 4). Movement of the cursor fully left or right from the center of the screen required a wrist flexion or extension of 60 degrees.

Figure 4: Hand position when holding the inertial mouse

The target left/right guidance cues were provided by the vibrotactile display only. No visual presentation of targets or the cursor was provided. A static background image from Ghost Recon depicting a virtual city scene looking across a street at a brick wall was displayed for the duration of the trials (map “m05_embassy.env”) (see Figure 5).

Figure 5: Static background image

The vibrotactile stimuli used a modulated 250 Hz sinusoidal signal held at a constant gain for all participants. This frequency was chosen because skin is most sensitive to light vibrations around 200 Hz (Verrillo, 1962), and maximum sensitivity for vibratory touch stimuli occurs from 200 to 400 Hz at stimulus intensities ranging from -20 to +60 dB (Verrillo, Fraioli, & Smith, 1969).

All participants reported the stimulus from both tactors as being distinct and comfortable. Modulation of the stimuli consisted of a stimulus interval (SI) of 100 msec and an inter stimulus interval (ISI) of 50 msec. White noise was presented via headphones to mask the sound of the mechanical relays used in the tactor driver.

Initial movement time (iMT), probability of correct initial movement direction (iMove), and time-stamped movement profiles were collected for each trial. iMT for this experiment is defined as the time in msec between target pop-up and the start of movement by the participant. iMove for this experiment is defined as the probability of making a correct initial movement toward the target by the participant. Movement profiles consisted of the time-stamped (in msec) ‘x’ screen coordinate of the center of the cursor recorded once every mouse tick. Mouse ticks only occur when there is movement of the mouse, with a maximum recording rate of about 100 mouse ticks per second for the described system.

Procedure

Participants were assigned to one of two orders of presentation of the TacPD condition. The participants were presented 2 blocks of 16 targets, for a total of 32 targets. Each target represented one trial. Upon completion of the first 16 trials, the tactor location was switched. Before each block of trials, the tactor placement was verified by obtaining the participant’s subjective perception of the discriminability and comfort of the tactors. This was accomplished by pulsing first one, then the other tactor, and having the participant point to the tactor they felt was activated. Upon completion of the trials, the participants were asked to fill out a questionnaire about their experience with computers and video games, and their experiences during the experiment.

For all trials the participants sat comfortably in front of the computer monitor in such a way that their hand holding the mouse would not touch the desk supporting the monitor. Participants were asked with which hand they normally used a computer mouse, and the tactors were applied as appropriate for each participant. Tactors were placed in line with the thumb and fourth finger at the base of the palm, either on the palmer or dorsal surface of the hand, depending on the block of trials. The tactors were held in place by a fabric strap wrapped around the hand. Participants had the tactors in contact with their hand for all trials.

Participants were instructed to depress and hold the inertial mouse mode button under the mouse with their index finger whenever they wanted to move the cursor. The participants then practiced using the inertial mouse to move the cursor fully left, right, up, and down by using only hand motions about the wrist. Though the tactors were in place during this practice, they were not active.

The primary task of the participants during a trial was to depress the inertial mouse mode button under the mouse and quickly move their hand in the direction of the target when they had an idea where the target was located. When a trial began, the tactile stimulus was presented. It continued to be presented until the trial ended. Irrespective of the correctness of the movement, each trial ended when the participant moved the cursor beyond the distance the target was located from the center of the screen. When each trial ended, the participant was to return his or her hand to a neutral, comfortable position and wait for the next trial to begin.

Results

The GLM in SPSS 11.5 was employed to analyze the two-way repeated measures design. All tests were run at the $\alpha = .05$ level.

Unambiguous intentional movements did not typically appear within 1 degree of hand movement, suggesting that the tolerance for identifying the initial movement could be widened to 8 pixels (1 degree of hand movement) rather than the 1 pixel tolerance employed by the data collection program. This 1 degree tolerance was applied to the iMT and iMove data.

There was no significant interaction between TacPD and TarLR on iMT (M_{PL} = 647.771; M_{PR} = 643.677; M_{DL} = 708.505; M_{DR} = 679.276; F(1,23) = .966, p > .05, η_p^2 = .040, $1\text{-}\beta$ = .156) (see Figure 6).

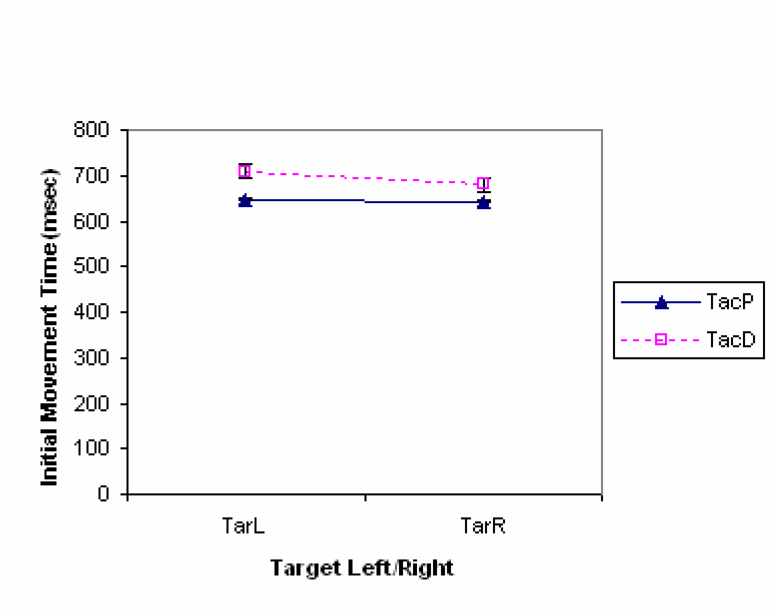


Figure 6: Interaction between TacPD and TarLR on iMT

The main effect of TacPD on iMT (see Figure 7) was not significant (M_{Palmer} = 645.724; M_{Dorsal} = 693.891; F(1,23) = 1.495, p > .05, η_p^2 = .061, $1\text{-}\beta$ = .216).

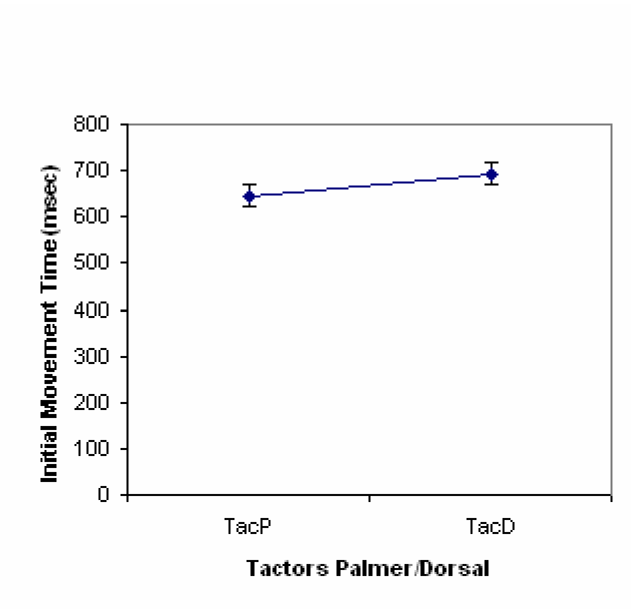


Figure 7: Main effect of TacPD on iMT

The main effect of TarLR on iMT (see Figure 8) was also not significant (M_{left} = 678.138; M_{right} = 661.477; F(1,23) = .961, p > .05, η_p^2 = .040, $1\text{-}\beta$ = .156).

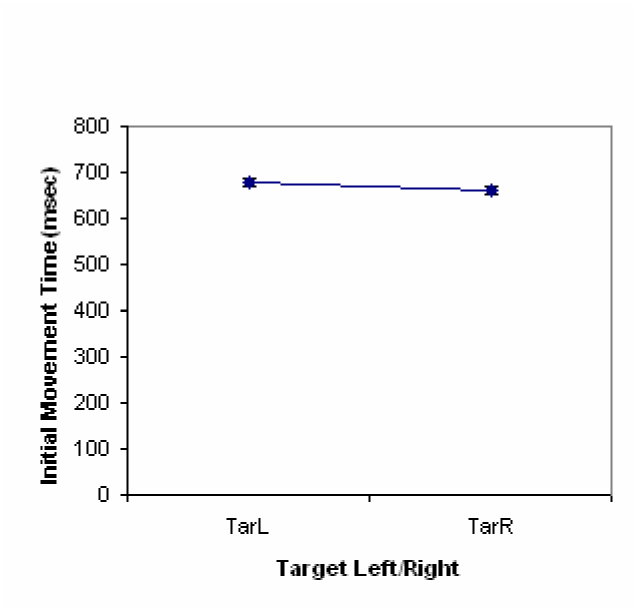


Figure 8: Main effect of TarLR on iMT

There was no significant interaction between TacPD and TarLR on iMove (M_{PL} = .776; M_{PR} = .755; M_{DL} = .734; M_{DR} = .682; F(1,23) = .195, p > .05, η_p^2 = .008, $1\text{-}\beta$ = .071) (see Figure 9).

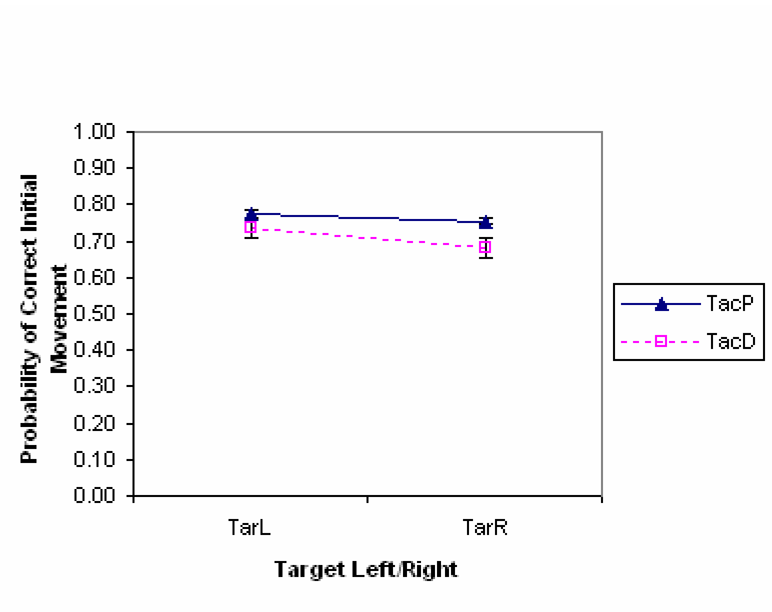


Figure 9: Interaction between TacPD and TarLR on iMove

The main effect of TacPD on iMove (see Figure 10) was not significant (M_{Palmer} = .766; M_{Dorsal} = .708; F(1,23) = 1.031, p > .05, η_p^2 = .043, $1\text{-}\beta$ = .164).

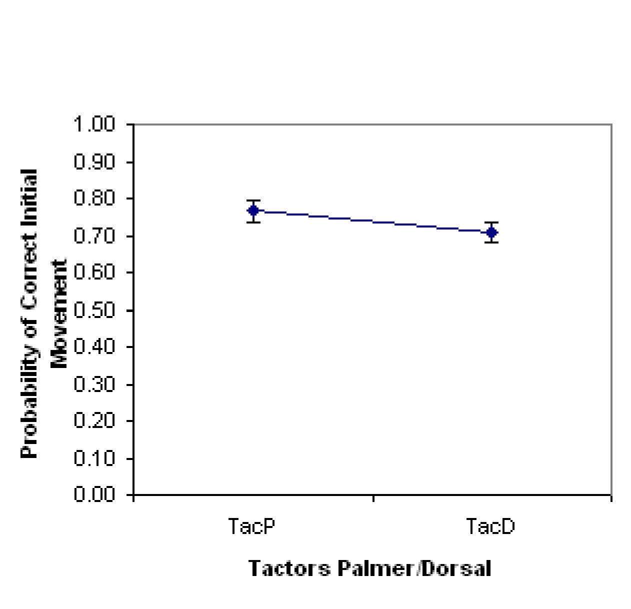


Figure 10: Effect of TacPD on iMove

The main effect of TarLR on iMove (see Figure 11) was also not significant (M_{left} = .755; M_{right} = .719; F(1,23) = 0.989, p > .05, η_p^2 = .041, $1-\beta$ = .159).

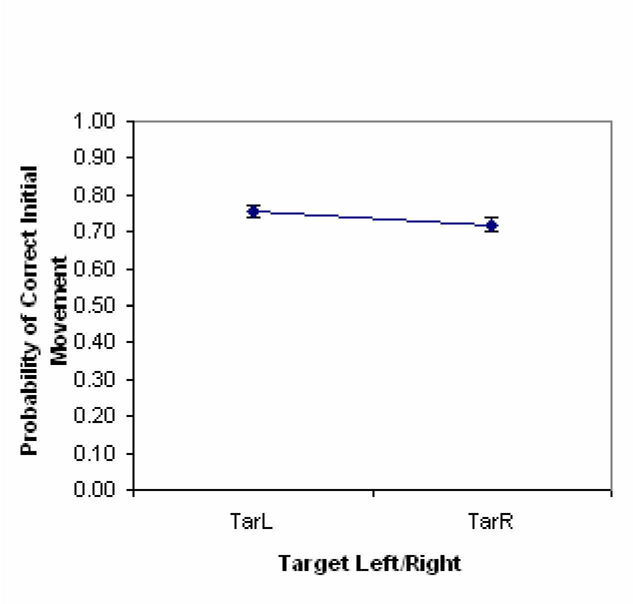


Figure 11: Effect of TarLR on iMove

Discussion

The data suggest that the affordance of vibrotactile guidance cues is independent of the location of the tactors on the hand when both tactors are located on the palmer or dorsal surface. Tactile cues provided on the left side of the hand (palm facing down) afford moving the hand to the left, while tactile cues provided on the right side of the hand afford moving the hand to the right. This affordance holds irrespective of whether the tactile cues are applied to the palmer or the dorsal surface of the hand.

Though effective for establishing the affordance of vibrotactile guidance cues applied to the same surface of the hand oriented with the palmer surface perpendicular to the floor, this experiment did not fully explore the affordance of these stimuli applied to opposite surfaces (e.g., one tactor palmer and one tactor dorsal) or with more diverse hand orientations. Since the tactors would most likely be applied to only one surface of the hand in TAGS (i.e., palmer or dorsal), our purpose for these studies was to establish, among other things, which surface of the hand should be employed for our given application rather than exploring the more fundamental affordance issues requiring an exhaustive analysis of the possible combinations of tactor placement, hand orientation, acceleration, visual stimuli, cognitive congruency, etc. Such a study would permit a more complete analysis of the possible shift between negative- and positive-feedback that may occur with multi-surface tactor placement spanning a wide range of hand orientations with respect to the floor.

CHAPTER THREE: EXPERIMENT 2

Experiment 2 established the affect of continuous relative distance cues and on- versus off-target vibrotactile stimuli on reaction time and accuracy for target selection.

For these studies, visual target cues were set against a visual background that must be searched. Tactile target cues were set against a relatively quiet background, and always correctly indicated the direction of the target. As such, it was expected that tactile target cues would facilitate target search, and that visual + vibrotactile direction and distance cues would result in faster time-to-target compared to visual cues only.

Initial pulse on target popup gives direction; increasing pulse rate gradient gives rapid feedback during near-target sub movements. Decreasing pulse rate gradient gives similar initial pulse cue on target popup, but less rapid feedback during near-target sub movements. Unlike the initial, ballistic movement from the origin to a location near the target, near-target sub movements are generally considered to be closed loop; feedback is useful for providing cues for determining relative-position near the target. Rapidly updating feedback close to the target should provide a more accurate indication of relative location as the user continues his or her target-selection task than feedback that is updated slowly. As such, it was expected that fast pulse rates near the target would result in faster time-to-target compared to slow pulse rates.

Design

The intent of Experiment 2 was to investigate the affect on affordance of tactile guidance cues of on-target versus off-target tactile guidance, and pulse rate gradient of the tactile stimulus sweeping up versus sweeping down as the cursor approaches the target. As such, Experiment 2 employed a 3 x 2 x 2 mixed factorial design (see Table 2).

Table 2: Outline of the design for Experiment 2

	Target Suppressed		Target Enhanced	
	Gradient UP	Gradient DOWN	Gradient UP	Gradient DOWN
Visual				
Tactile				
Visual+Tactile				

The within-subjects variable was Display (visual, tactile, and visual + tactile). Between-subjects variables included TarSE (Target Suppressed or Enhanced) and GraUD (pulse rate gradient sweeps Up or Down as the cursor approaches the target). Target Suppressed refers to the tactors being activated only when the cursor is off the target; when the cursor is on the target, the tactile display is turned off. Target Enhanced refers to the tactors being activated when the cursor is both off and on the target; when the cursor is on the target, both tactors are activated at the same time. Pulse rate gradient sweeps Up refers to increasing the pulse rate as the cursor gets closer to the target; the farther the cursor is from the target, the slower the pulse rate. Pulse rate gradient sweeps Down, conversely, refers to decreasing the pulse rate as the cursor gets closer to the target; the farther the cursor is from the target, the faster the pulse rate.

Participants

The 24 undergraduate students at the University of Central Florida who participated in Experiment 1 also participated in this experiment. Hence, there were 12 males and 12 females in the sample. Though 3 males and 1 female stated that they write with their left hand, all participants stated that they use their right hand for mouse operations. Each participant performed both experiments on the same day. A short break was offered between the experiments, but all participants declined.

Apparatus

The software supporting this effort ran on a 3.00 GHz Dell Dimension 8300 with the Windows XP Professional operating system. Screen and color resolution was fixed at 1024 x 768 and 32-bit, respectively. A Dell M992 18 inch monitor was used to project the visual display. A Gyration Ultra inertial mouse was plugged into the high-speed USB port on the computer and functioned like a conventional three-button mouse with a scrolling wheel. The vibrotactile tactor system included two EAI C2 tactors, a tactor driver, and a Velcro strap for positioning the tactors. The computer sends commands and a 250 Hz sinusoid signal to the driver, which in turn drives the tactors (see Figure 12).

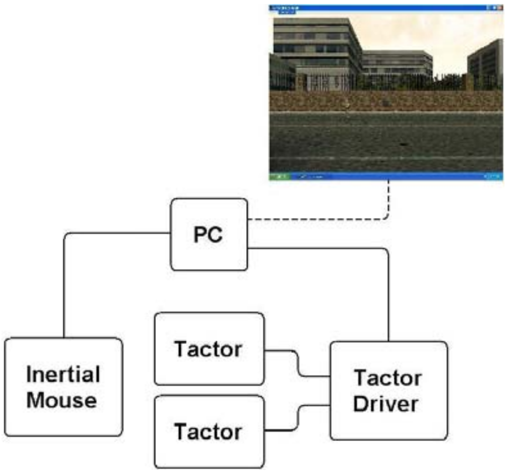


Figure 12: Block diagram of the system

In keeping with the Fitts movement-time paradigm, the software presented 2 sizes of targets (small and large) at 4 horizontal locations (2 left of center, and 2 right of center). Targets consisted of a soldier from the Ghost Recon game holding an AK-74 pointed at the participant (actor “m05_eli_ak74_1.atr”) (see Figure 13).

Figure 13: Visual Target

The target was captured in perspective for each target location and size, and included a shadow. Small targets were 14 pixels wide; large targets were 28 pixels wide. The centers of mass of the target positions were located 423 pixels from the center of the display for the farthest targets, and 169 pixels from the center of the display for the closest targets. The order of presentation of the 8 targets was partially counterbalanced using the Latin Square technique for each participant.

The cursor was depicted as a white ‘+’ 19 pixels across, and always started a trial in the center of the screen. The cursor was constrained by the software to move only in the horizontal plane passing through the center of the screen and the center of mass of all targets.

The inertial mouse was used in its optical mouse mode on the desk surface in front of the monitor. Tactors were positioned on either side of the mouse such that the thumb and third finger were in direct contact with the tactors’ vibrating elements (see Figure 14). Movement of the mouse required to put the cursor onto the nearest targets required a 2.5-inch movement of the mouse from the point of origin. Movement of the mouse required to put the cursor onto the farthest targets required a 5.0-inch movement of the mouse from the point of origin.

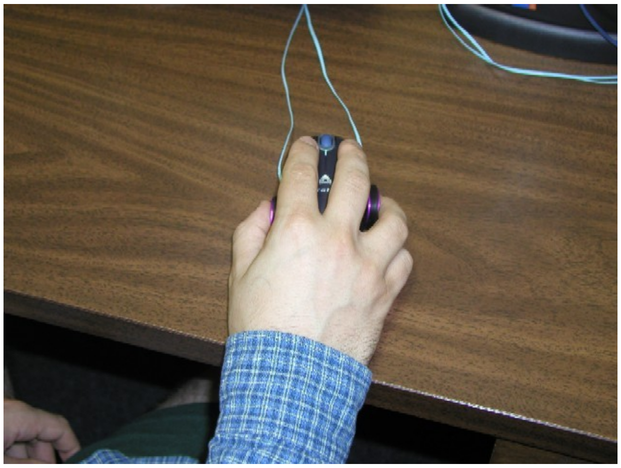


Figure 14: Hand position using the inertial mouse supported by the desk

The target left/right guidance cues were provided by the visual display, by the tactile display, or by both the visual and tactile display, depending on the block of trials. A static background image from Ghost Recon depicting a virtual city scene looking across a street at a brick wall was displayed for the duration of the trials (map “m05_embassy.env”) (see Figure 15).

Figure 15: Static background image

The vibrotactile stimuli used a modulated 250 Hz sinusoidal signal held at a constant gain for all participants. This frequency was chosen because skin is most sensitive to light vibrations around 200 Hz (Verrillo, 1962), and maximum sensitivity for vibratory touch stimuli occurs from 200 to 400 Hz at stimulus intensities ranging from -20 to +60 dB (Verrillo, Fraioli, & Smith, 1969). The pulse rate was defined by varying the inter stimulus interval (ISI) of the vibrotactile stimulus. The rising and falling of the pulse rate with distance from the target was driven by a 3rd order polynomial function ranging from ISIs of 250 msec to 10 msec (see Figure 16).

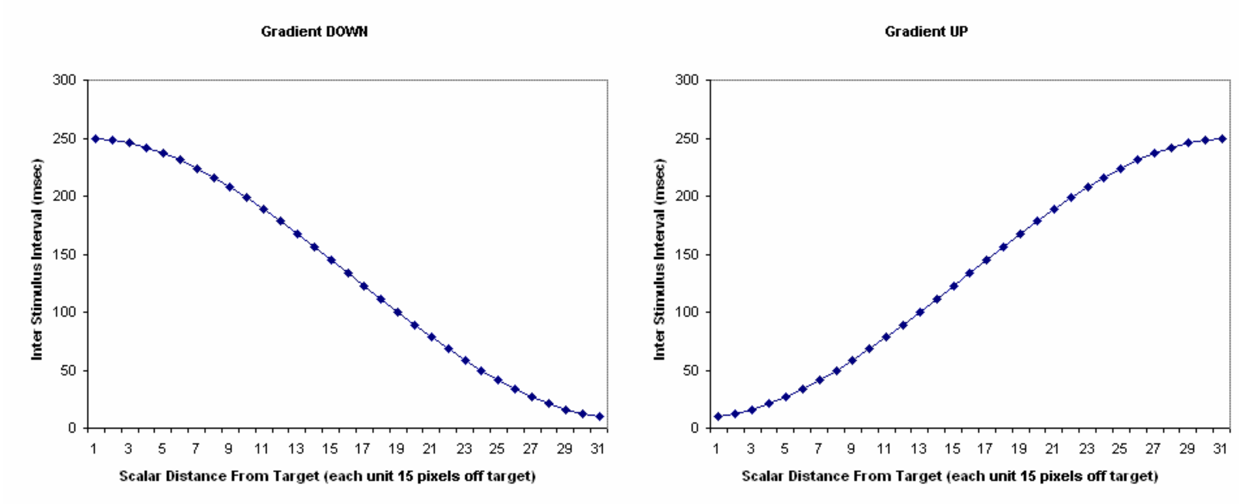


Figure 16: Inter Stimulus Interval x Scalar Distance from Target

The distribution of ISIs by distance from target was obtained by fitting a curve to the average movement profile from Experiment 1. This distribution was applied whenever the cursor was within 60 degrees of the target; beyond 60 degrees the ISI was constant at either 250 msec or 10 msec. A stimulus interval of 100 msec was applied to the tactile stimuli irrespective of the ISI. All participants had a 100% detection rate for the tactile stimuli. All participants reported the stimulus from both tactors as being distinct and comfortable. White noise was presented via headphones to mask the sound of the mechanical relays used in the tactor driver.

Raw initial movement time (iMT), raw probability of correct initial movement (iMove), the number of times on-target (otCnt), time from target pop-up to target drop (ST), and time-stamped movement profiles were collected for each trial. iMT for this experiment is defined as the time in msec between target pop-up and the start of movement by the participant. iMove is the probability of a correct initial movement toward the target by the participant. otCnt is defined as the number of times the cursor went from off-target to on-target. ST is the time in msec from target pop-up to target drop. Movement profiles consisted of the time-stamped (in msec) horizontal screen coordinate of the center of the cursor recorded once every mouse tick. Mouse ticks only occur when there is movement of the mouse, with a maximum recording rate of about 100 mouse ticks per second for the described system.

Procedure

Participants were randomly assigned to one of four groups: target suppressed, gradient UP; target suppressed, gradient DOWN; target enhanced, gradient UP; and target enhanced, gradient DOWN. The participants were presented 3 blocks of 32 targets, for a total of 96 targets. Each presentation of a target represents one trial. The first block of trials was visual only, the second block of trials was tactile only, and the third block of trials was visual and tactile. Order of presentation of the blocks was not varied in this experiment. Before each block of trials, the instructions specific for the next block of trials were briefly reviewed. Upon completion of the experiment, the participants were asked to fill out a questionnaire about their experience with computers and video games, and their experiences during the experiment.

For all trials the participants sat comfortably in front of the computer monitor in such a way that their hand could comfortably move the mouse on the desk. The monitor was positioned approximately 21 inches from the bridge of the participant’s nose. Tactors were positioned on the sides of the mouse such that the thumb and third finger were in direct contact with the vibrating element on the tactors. Participants had the tactors in contact with their fingertips for all trials.

The primary task of the participants during a trial was to quickly move the cursor onto the target when they had an idea where the target was located, and clicking the left mouse button. When a trial began, the target stimuli were presented as appropriate for the block. The stimuli continued to be presented until the trial ended. Each trial ended when the participant clicked on the target. The next trial began after a random delay ranging from 2 to 9 seconds.

Results

The GLM in SPSS 11.5 was employed to analyze the 3 x 2 x 2 mixed factorial design. Fisher's LSD was employed on all post-hoc analyses. All tests were run at the $\alpha = .05$ level.

Initial Movement Time (iMT)

The results for iMT are presented in Table 3. Means for the Display x TarSE x GraUD interaction are presented in Table 4. Figure 17 depicts the significant Display x TarSE x GraUD interaction.

Table 3: Results for raw initial movement time (msec)

Source	SS	*df*	ms	*F*	*p*	η_p^2	*1-β*
Total	566043.922	71	--	--	--	--	--
Between Subjects	207313.992	23	--	--	--	--	--
TarSE	3346.643	1	3346.643	0.333	ns	0.016	0.085
GraUD	3087.670	1	3087.670	0.308	ns	0.015	0.083
TarSE x GraUD	133.049	1	133.049	0.013	ns	0.001	0.051
Errorb	200746.631	20	10037.332	--	--	--	--
Within Subjects	358729.930	48	--	--	--	--	--
Display	186294.635	2	93147.318	33.350	<.05	0.625	1.000
Display x TarSE	20366.885	2	10183.443	3.646	<.05	0.154	0.639
Display x GraUD	3771.514	2	1885.757	0.675	ns	0.033	0.156
Display x TarSE x GraUD	36574.319	2	18287.159	6.547	<.05	0.247	0.887
Errorw	111722.576	40	2793.064	--	--	--	--

Table 4: Means for Display x TarSE x TacNF on iMT

	Vis	Tac	Vis+Tac
TarS/GraU	410.948	377.313	293.417
TarS/GraD	344.354	422.656	267.219
TarE/GraU	427.344	409.542	277.542
TarE/GraD	435.073	332.969	315.250

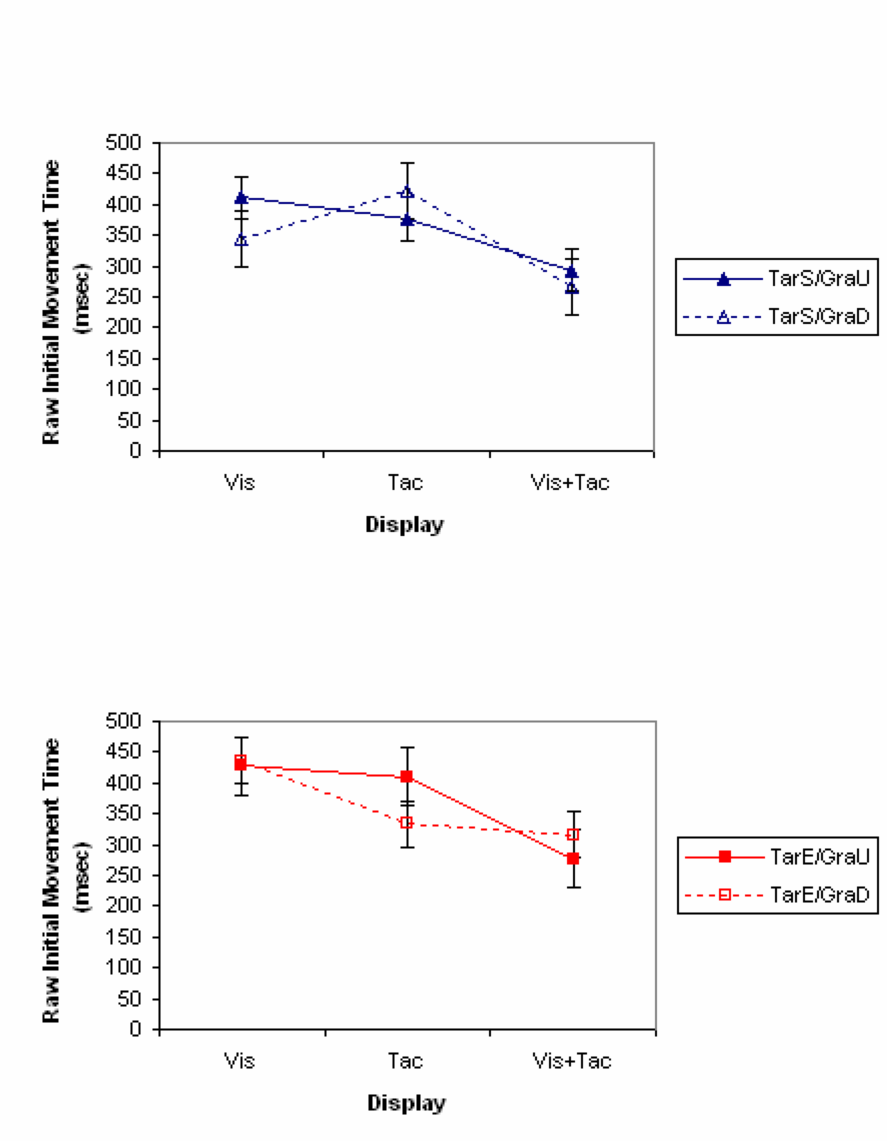


Figure 17: Display x TarSE x TacNF on iMT

For both gradient up (GraU) and gradient down (GraD) at suppressed targets (TarS), the visual-only and tactile-only guidance cues resulted in longer iMT than the combined visual + tactile guidance cues; visual-only was not significantly different from tactile-only. For GraU at enhanced targets (TarE), the visual-only and tactile-only guidance cues resulted in longer iMT than the combined visual + tactile guidance cues. For GraD at TarE, the visual-only guidance cues resulted in longer iMT than tactile-only and the combined visual + tactile guidance cues; tactile-only was not significantly different from the combined guidance cues. TarS/GraD resulted in longer iMT than TarE/GraD at tactile-only.

Selection Time (ST)

The results for ST are presented in Table 5. Means for the Display x TarSE interaction are presented in Table 6. Figure 18 depicts the non significant Display x TarSE x GraUD interaction. Figure 19 depicts the significant Display x TarSE interaction.

Table 5: Results for Time from Pop-Up to Drop (msec)

Source	SS	*df*	ms	*F*	*p*	η_p^2	*1-β*
Total	826385362.242	71	--	--	--	--	--
Between Subjects	138783153.596	23	--	--	--	--	--
TarSE	42743969.063	1	42743969.063	11.017	<.05	0.355	0.884
GraUD	8481922.071	1	8481922.071	2.186	ns	0.099	0.291
TarSE x GraUD	9959416.949	1	9959416.949	2.567	ns	0.114	0.332
Errorb	77597845.513	20	3879892.276	--	--	--	--
Within Subjects	687602208.646	48	--	--	--	--	--
Display	441362471.881	2	220681235.941	64.920	<.05	0.764	1.000
Display x TarSE	79018849.743	2	39509424.872	11.623	<.05	0.368	0.990
Display x GraUD	14132743.636	2	7066371.818	2.079	ns	0.094	0.402
Display x TarSE x GraUD	17116393.052	2	8558196.526	2.518	ns	0.112	0.475
Errorw	135971750.334	40	3399293.758	--	--	--	--

Table 6: Means for Display x TarSE on ST

	Vis	Tac	Vis+Tac
TarS	1390.286	4395.182	1340.813
TarE	1455.234	8899.255	1394.776

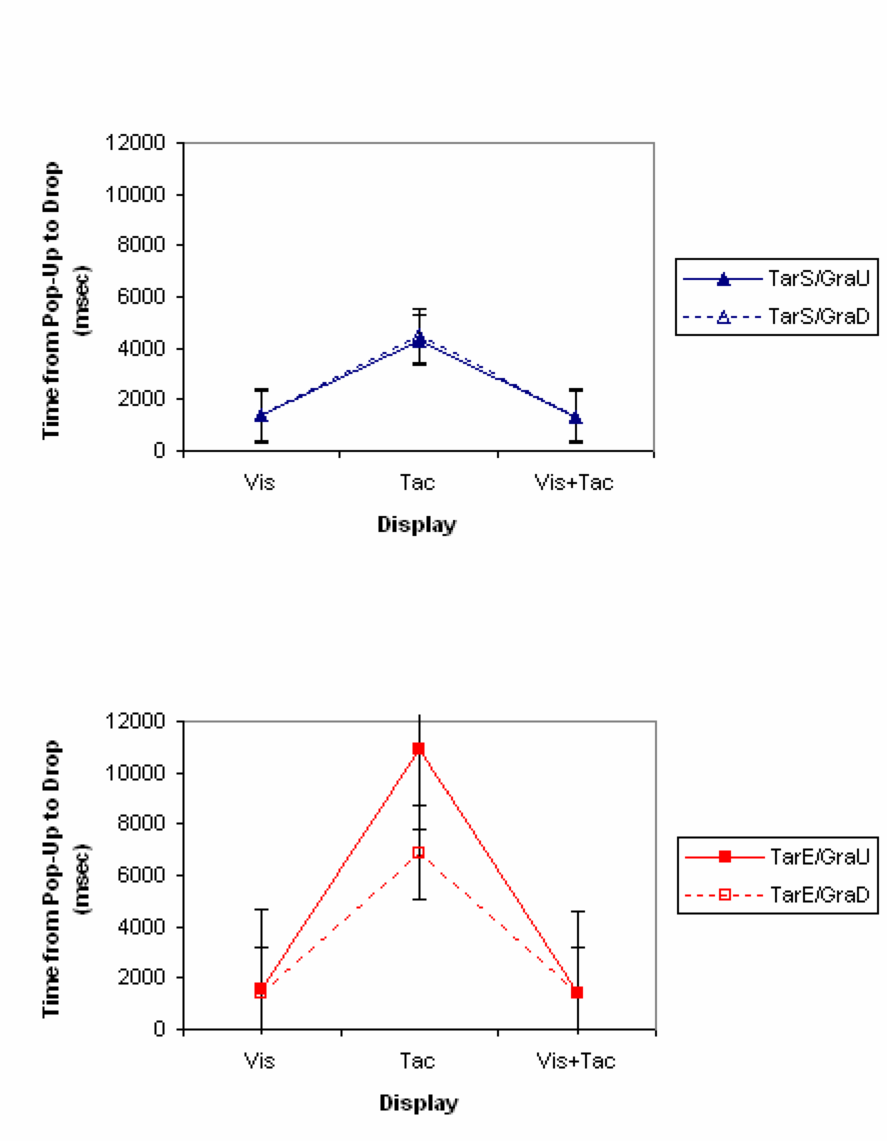


Figure 18: Display x TarSE x GraUD on ST

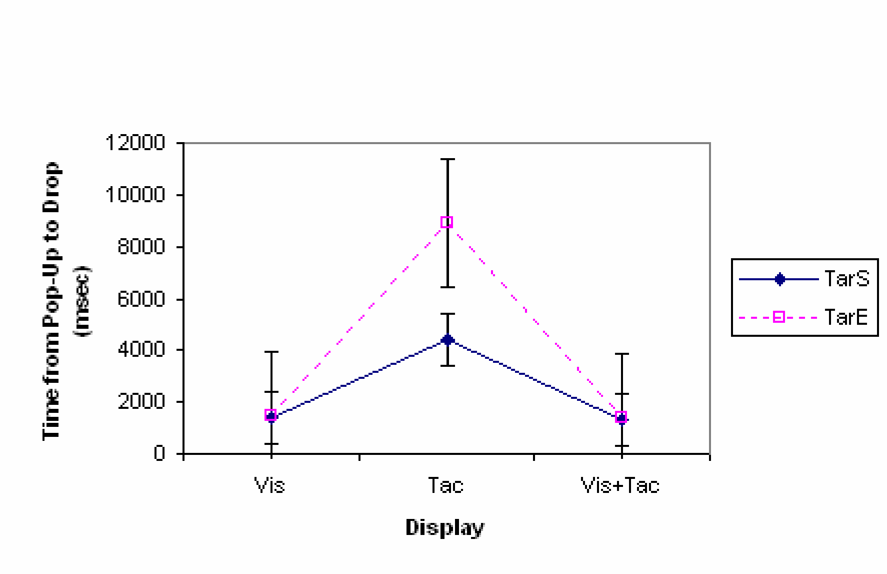


Figure 19: Display x TarSE on ST

TarE was significantly slower than TarS for tactile-only. TarS and TarE at tactile-only were significantly slower than at visual and visual + tactile.

On-Target Count (otCnt)

The results for otCnt are presented in Table 7. Means for the Display x TarSE x GraUD interaction are presented in Table 8. Figure 20 depicts the significant Display x TarSE x GraUD interaction.

Table 7: Results for number of times cursor moves from off- to on-target

Source	**SS**	***df***	**ms**	***F***	***p***	η_p^2	$1\text{-}\beta$
Total	148.456	71	--	--	--	--	--
Between Subjects	25.138	23	--	--	--	--	--
TarSE	6.608	1	6.608	11.309	<.05	0.361	0.892
GraUD	3.204	1	3.204	5.482	<.05	0.215	0.606
TarSE x GraUD	3.639	1	3.639	6.228	<.05	0.237	0.661
Errorb	11.687	20	0.584	--	--	--	--
Within Subjects	123.318	48	--	--	--	--	--
Display	83.371	2	41.685	70.895	<.05	0.780	1.000
Display x TarSE	8.087	2	4.043	6.877	<.05	0.256	0.902
Display x GraUD	3.707	2	1.854	3.153	ns	0.136	0.572
Display x TarSE x GraUD	4.634	2	2.317	3.940	<.05	0.165	0.675
Errorw	23.520	40	0.588	--			

Table 8: Means for Display x TarSE x GraUD on otCnt

	Vis	Tac	Vis+Tac
TarS/GraU	1.198	2.698	1.167
TarS/GraD	1.177	2.802	1.167
TarE/GraU	1.396	5.417	1.417
TarE/GraD	1.146	3.188	1.281

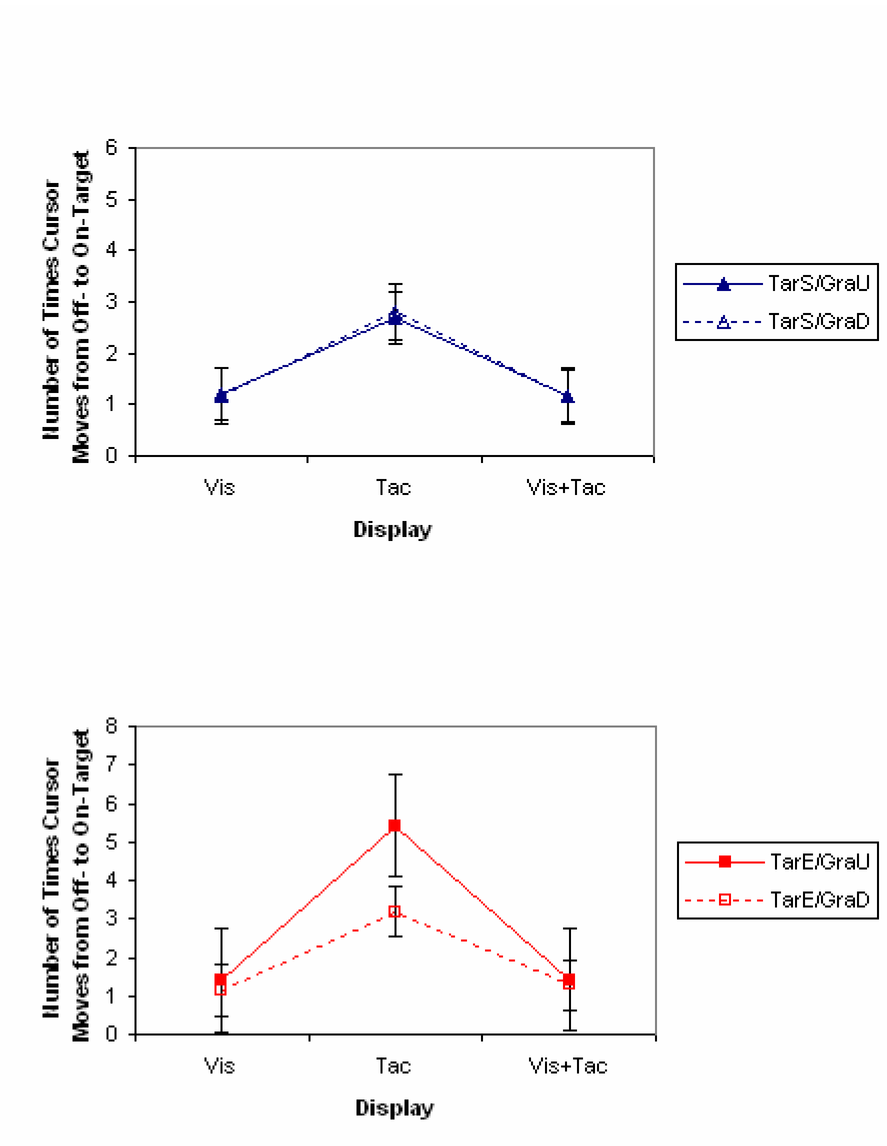


Figure 20: Display x TarSE x GraUD on otCnt

For both GraU and GraD at TarS, the tactile-only guidance cues resulted in a larger otCnt than the visual-only and combined visual + tactile guidance cues; visual-only was not significantly different from visual + tactile. For GraU at TarE, the tactile-only guidance cues resulted in a larger otCnt than the visual-only and combined visual + tactile guidance cues;

visual-only was not significantly different from visual + tactile. For GraD at TarE, the tactile-only guidance cues resulted in a larger otCnt than the visual-only and visual + tactile. The visual-only guidance cues resulted in a lower otCnt than visual + tactile.

TarS/GraU resulted in a lower otCnt than TarE/GraU at tactile-only and visual + tactile. TarS/GraD resulted in a lower otCnt than TarE/GraU at tactile-only and visual + tactile. TarS/GraD also resulted in a lower otCnt than TarE/GraD at tactile-only. TarE/GraD resulted in a lower otCnt than TarE/GraU at tactile-only.

Probability of Correct Initial Movement (iMove)

The results for iMove are presented in Table 9. Figure 21 depicts the Display x TarSE x GraUD interaction.

Table 9: Results for probability of correct initial movement

Source	**SS**	***df***	**ms**	***F***	***p***	η_p^2	$1-\beta$
Total	0.129	71	--	--	--	--	--
Between Subjects	0.046	23	--	--	--	--	--
TarSE	0.002	1	0.002	1.111	ns	0.053	0.171
GraUD	0.005	1	0.005	3.086	ns	0.134	0.387
TarSE x GraUD	0.003	1	0.003	1.975	ns	0.090	0.268
Errorb	0.035	20	0.002	--	--	--	--
Within Subjects	0.083	48	--	--	--	--	--
Display	0.008	2	0.004	2.346	ns	0.105	0.447
Display x TarSE	0.001	2	0.001	0.370	ns	0.018	0.105
Display x GraUD	0.003	2	0.002	0.864	ns	0.041	0.188
Display x TarSE x GraUD	0.000	2	0.000	0.123	ns	0.006	0.068
Errorw	0.070	40	0.002	--	--	--	--

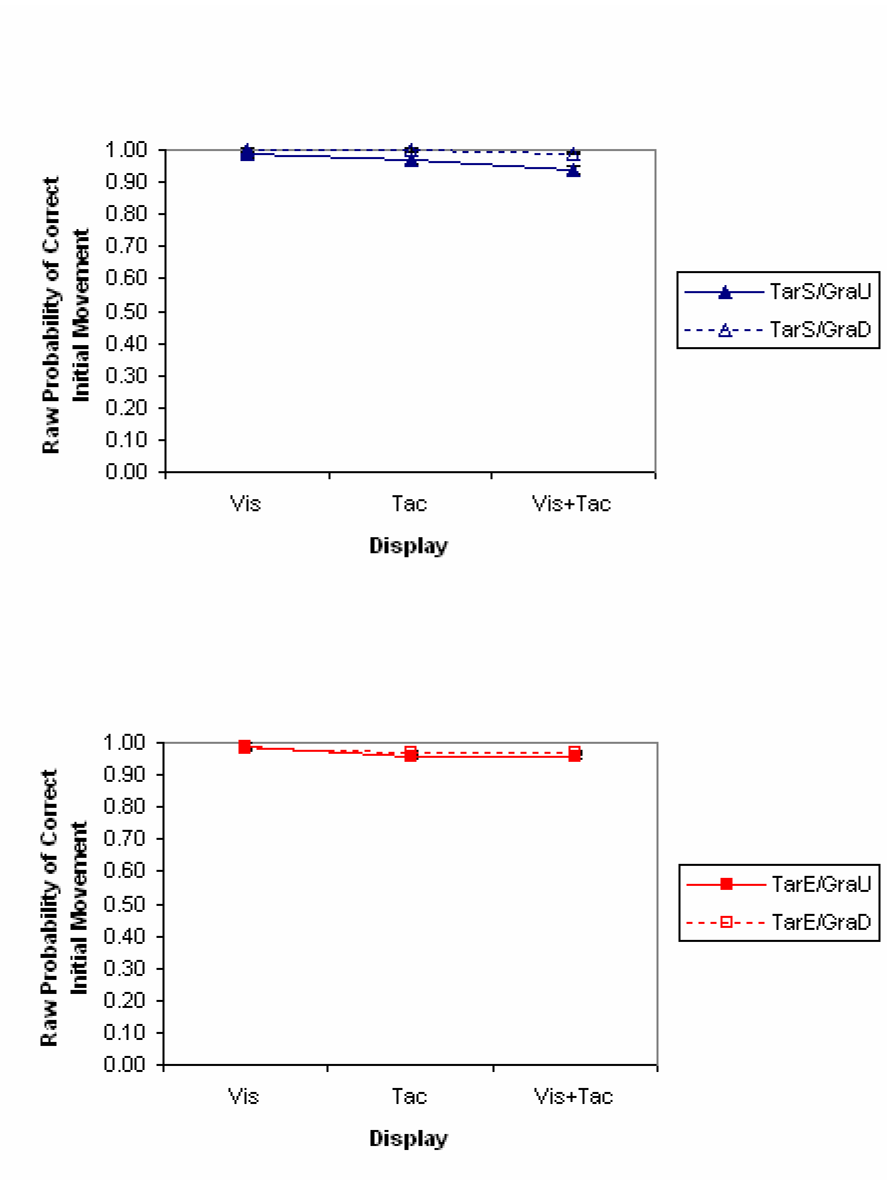


Figure 21: Display x TarSE x GraUD on iMove

Discussion

The data suggest that there may be an interaction between the gradient of vibrotactile stimuli and the method used to highlight an “on-target” condition. The suppressed target condition was superior to the enhanced target condition. This is particularly true when the pulse rate increases as the cursor moves closer to a target.

This experiment employed a target-enhanced condition that pulsed at the same rate as the guidance cues provided immediately to either side of the target. No data are provided by this experiment that suggest how performance changes when the target-enhanced condition pulses at the opposite rate as the guidance cues. Such an extreme variation in near-target versus on-target cues may null any differences between the suppressed and enhanced target conditions. SME comments also suggest that continuous display of distance and direction may not be as useful (or desirable) as discrete distance and direction cues. Likewise, research has suggested that the visual display is not necessary for the entire duration of the movement of a fast target-selection task (Jeannerod & Prablanc, 1983; Carlton, 1981). Rather, feedback providing relative distance information must be provided near the target for any high degree of accuracy in target selection. Providing higher resolution feedback (ISI < 100 msec) should improve target selection accuracy compared to lower resolution feedback (ISI > 100 msec).

As a byproduct of the programming methods used to track timing and changes in mouse position, this experiment and Experiment 1 created movement profiles that, while spatially accurate, were temporally inaccurate. The methods employed permit a time-stamped update of the mouse position roughly once every 10 msec. A large number of mouse movements could have been recorded by the software during this time, but the timing was not updated at rates less than 10 msec. This lag in update times resulted in sets of records where the mouse position changed but the time stamp did not change. As such, development of velocity and acceleration profiles was problematic at best; only the spatial profiles could be investigated with a high degree of accuracy.

CHAPTER FOUR: EXPERIMENT 3

Experiment 3 established the cueing effectiveness of vibrotactile guidance cues on the hand by employing the Fitts movement-time paradigm (Fitts, 1954; Fitts & Peterson, 1964; Fitts & Radford, 1966; Jagacinski, Pepperger, Moran, Ward, & Glass, 1980). Specifically, this study investigated discrete versus continuous vibrotactile relative distance cues, and on- versus off-target vibrotactile stimuli. Two hypotheses were explored in this experiment.

From the study of JND's in audition, vision, and tactile perception (Friberg & Sundberg, 1995; Drake & Botte, 1993; Orban, Van Calenbergh, de Bruyn, & Maes, 1985; Stevens, 1959; Mowbray & Gebhard, 1955), we know that temporally based perception requires some minimum level of change or difference between stimuli. When you maximize the difference between two stimuli, you maximize the chance of detecting that difference. We achieve this maximum difference for our application by making sure that the on-target stimuli is as different as possible from the near-target guidance cues. This translates into having a fast pulse rate (e.g., ISI = 10 msec) near the target with either an absence of vibrotactile stimuli on-target or a slow pulse rate (e.g., ISI = 250 msec) on-target from both of the tactors. We can also have a slow pulse rate presented near the target with the fast pulse rate on-target. Minimum difference between the on-target and near-target stimuli occurs when the on-target and near-target pulse rates are the same. With this in mind, using the absence of vibrotactile stimuli on-target with the slow pulse rate near the target should result in an intermediate level of difference between the on-target and near-target stimuli. It is thus expected that variation in pulse rate when moving On/Off the target will result in shorter time-on-target than no variation in pulse rate.

Prior research has suggested that visual guidance for target selection is required only at initial movement and at the end of the initial movement during target closure (Jeannerod & Prablanc, 1983; Carlton, 1981). The off-target vibrotactile pulse rates with ISI's in excess of 100 msec used in Experiment 2 may already be providing this discrete form of guidance. When a target was presented, the initial, rapid ballistic movement made by the participants bypassed the slow pulse rates far from the target. At the end of the ballistic movement, the near-target pulse rates were such that several pulses would have been felt during the sub-movements leading to final target selection, providing the needed guidance cues to close on the target. As such, it is expected that discontinuous vibrotactile direction and distance cues will result in identical target selection times to continuous vibrotactile direction and distance cues.

Design

The intent of this experiment was to establish if there are performance differences between discrete and continuous distance information for target selection, and investigate the interaction between the near-target pulse rate and on-target cues. This Experiment 1lso was to establish if there are performance differences between tactile and visual + tactile. As such, this experiment employed a 2 x 3 x 2 x 2 mixed factorial design (see Table 10).

Table 10: Outline of the proposed design for Experiment 3

		Continuous		Discrete	
		Gradient UP	Gradient DOWN	Gradient UP	Gradient DOWN
Vis + Tac	Suppressed				
	Slow Enhanced				
	Fast Enhanced				
Tac	Suppressed				
	Slow Enhanced				
	Fast Enhanced				

The within-subjects variables include Visual + Tactile or Tactile (Display), and Target Suppressed, Target Enhanced Slow, or Target Enhanced Fast (TarSEsf). Target Suppressed refers to the tactors being activated only when the cursor is off the target; when the cursor is on the target, the tactile display is turned off. Target Enhanced Slow refers to the tactors being activated at the slowest pulse rate when the cursor is on the target; when the cursor is on the target, both tactors are activated at the same time with a slow pulse rate. Target Enhanced Fast refers to the tactors being activated at the fastest pulse rate when the cursor is on the target; when the cursor is on the target, both tactors are activated at the same time with a fast pulse rate.

Between-subjects variables include Gradient Continuous or Gradient Discrete (GraCDi), and pulse rate Gradient sweeps UP or pulse rate Gradient sweeps DOWN (GraUDo). Pulse rate Gradient sweeps UP refers to increasing the pulse rate (decreasing ISI) as the cursor gets closer to the target; the farther the cursor is from the target, the slower the pulse rate (increasing ISI). Pulse rate Gradient sweeps DOWN, conversely, refers to decreasing the pulse rate (increasing

ISI) as the cursor gets closer to the target; the farther the cursor is from the target, the faster the pulse rate (decreasing ISI).

Figure 22 graphically depicts TarSEsf x GraCDi x GraUDo. The height of the curves represents the duration of ISI, where higher points on the curves represent longer ISI. The width of the curves represents the scalar distance from the target, where the target is in the center of convergence of each set of curves. TarSEsf is represented by the blank space or mixed-color bar between the converging curves. GraCDi is represented by the continuity of the curves; the left set of curves is Continuous, while the right set is Discrete. Finally, GraUDo is represented by the height of the curves at the center of convergence of the set of curves. Since both Display conditions contain identical versions of this interaction, the Display conditions are not depicted in Figure 22.

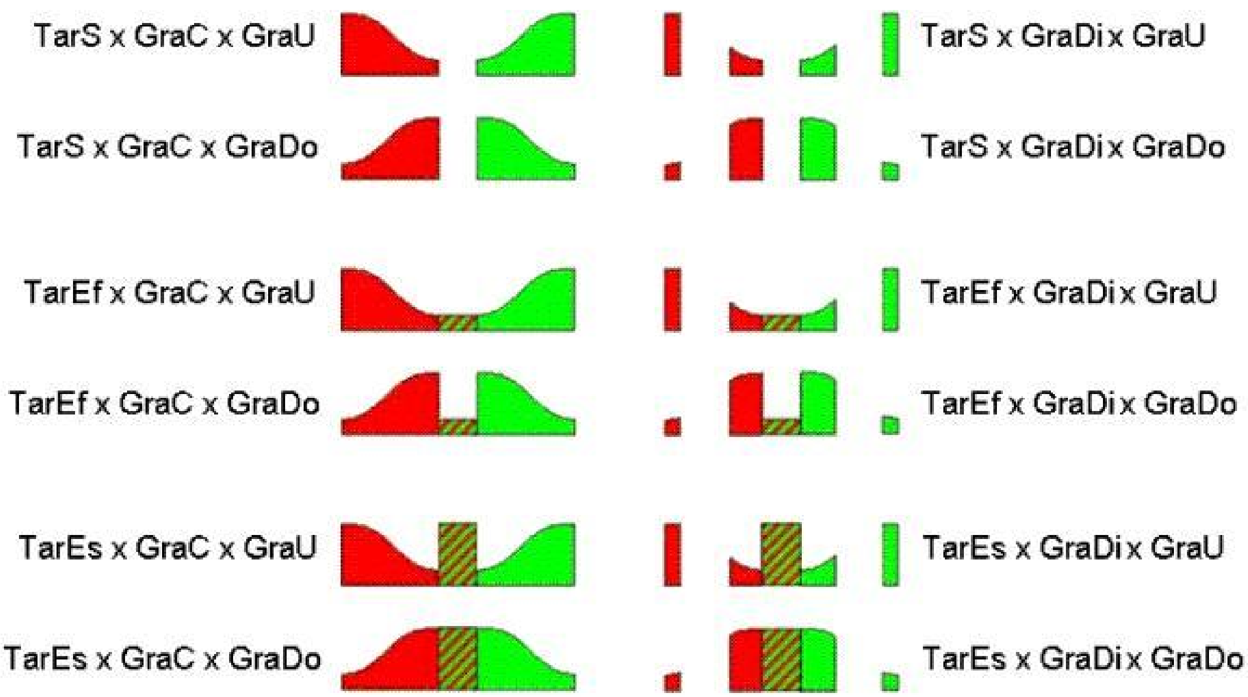


Figure 22: Graphical depiction of design for Experiment 3

Participants

32 undergraduate students at the University of Central Florida participated in this experiment. There were 9 male participants and 23 female participants in this sample. Participants' handedness was measured using the Edinburgh Handedness Inventory (Oldfield, 1971). A participant questionnaire collected data about their experience with computers and video games. Though no male participants and 3 female participants indicated that they have a left-hand bias, all participants chose to use the mouse with their right hand.

Participants were assigned to an order of presentation of the within-subjects conditions by Latin Square. Each participant was assigned to the next order of presentation of the Display conditions in the Display Latin Square. Each participant was then assigned the next order of presentation of the TarSEsf conditions in the TarSEsf Latin Square.

Apparatus

The software supporting this effort ran on a 3.00 GHz Dell Dimension 8300 with the Windows XP Professional operating system. Screen and color resolution was fixed at 1024 x 768 and 32-bit, respectively. A Dell M992 18 inch monitor was used to project the visual display. A Gyration Ultra inertial mouse was plugged into the high-speed USB port on the computer and functioned like a conventional three-button mouse with a scrolling wheel. The vibrotactile tactor system included two EAI C2 tactors, a tactor driver, and a Velcro strap for positioning the tactors. The computer sends commands and a 250 Hz sinusoid signal to the driver, which in turn drives the tactors (see Figure 23).

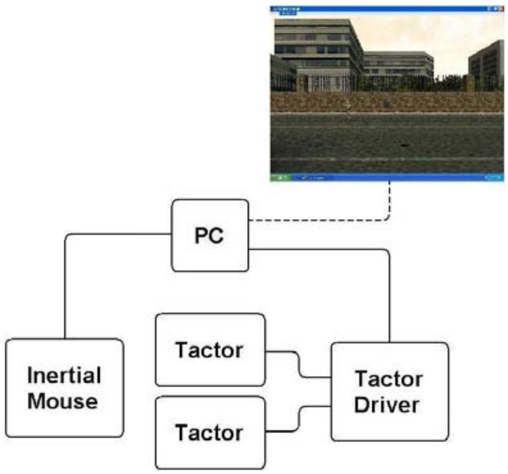


Figure 23: Block Diagram of the system

The software presented 2 sizes of targets (small and large) at 4 horizontal locations (2 left of center and 2 right of center). Targets consisted of a soldier from the Ghost Recon game holding an AK-74 pointed at the participant (actor “m05_eli_ak74_1.atr”) (see Figure 24).

Figure 24: Visual Target

The target was captured in perspective for each target location and size, and included a shadow. Small targets were 14 pixels wide; large targets were 28 pixels wide. The centers of mass of the target positions were located 423 pixels from the center of the display for the farthest targets, and 169 pixels from the center of the display for the closest targets. The order of presentation of the 8 targets was partially counterbalanced using the Latin Square technique for each participant. A random 2 to 9 second ISI occurred between target drop and target pop-up.

The cursor was depicted as a white ‘+’ 19 pixels across, and always started a trial in the center of the screen. The cursor was constrained by the software to move only in the horizontal plane passing through the center of the screen and the center of mass of all targets.

The inertial mouse was used in its optical mouse mode on the desk surface in front of the monitor. Movement of the mouse required to put the cursor onto the nearest targets required a 2.5-inch movement of the mouse from the point of origin. Movement of the mouse required to put the cursor onto the farthest targets required a 5.0-inch movement of the mouse from the point of origin.

The target left/right guidance cues were provided by the visual + tactile display or tactile-only display, depending on the block of trials. A static background image from Ghost Recon depicting a virtual city scene looking across a street at a brick wall was displayed for the duration of the trials (map “m05_embassy.env”) (see Figure 25).

Figure 25: Static background image

The vibrotactile stimuli used a modulated 250 Hz sinusoidal signal held at a constant gain for all participants. This frequency was chosen because skin is most sensitive to light vibrations around 200 Hz (Verrillo, 1962), and maximum sensitivity for vibratory touch stimuli occurs from 200 to 400 Hz at stimulus intensities ranging from -20 to +60 dB (Verrillo, Fraioli, & Smith, 1969).

The pulse rate of the vibrotactile signal was defined in real-time by varying the inter stimulus interval (ISI) of the vibrotactile stimulus. The rising and falling of the pulse rate with distance from the target was driven by a 3rd order polynomial function ranging from ISIs of 250 msec to 10 msec (see Figure 26).

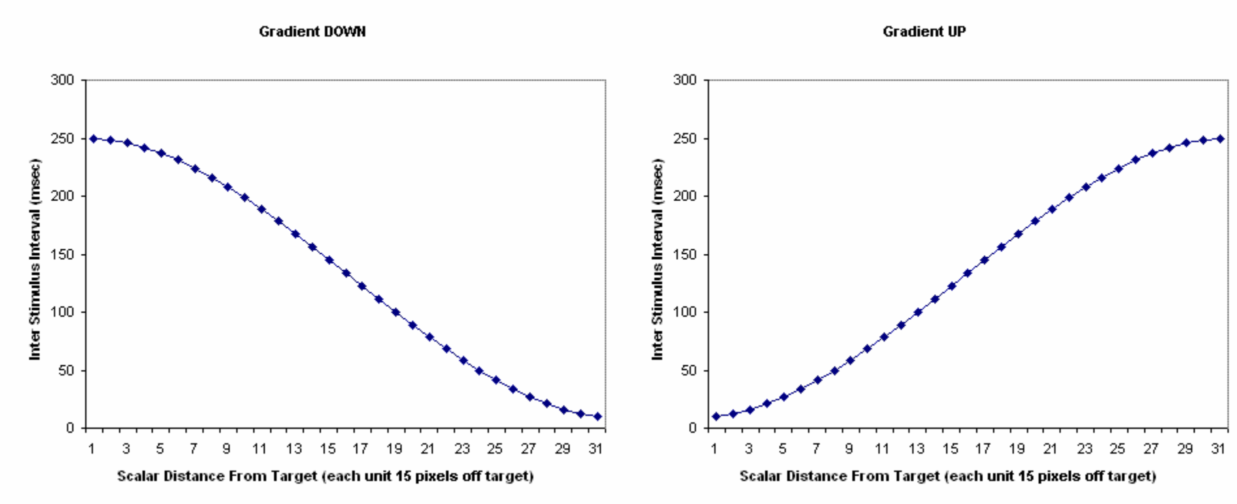


Figure 26: Continuous Inter Stimulus Interval x Scalar Distance from Target

The distribution of ISIs by distance from target was obtained by fitting a curve to the average movement profile from Experiment 1. This distribution was applied whenever the cursor was within 60 degrees of the target; beyond 60 degrees the ISI was constant at either 250 msec or 10 msec.

For the Discrete Gradient condition (see Figure 27), movements toward the target within 105 pixels of the nearest edge of the target resulted in a continuous tactile display. Likewise, from target pop-up to 8 pixels of movement toward the target, the tactile display was presented continuously. These distances were estimated from the average movement profile from Experiment 1. They reflect the end of the first ballistic movement, and the tolerance for establishing unambiguous initial movement, respectively. Movement away from the target resulted in a continuous tactile display with ISI following the gradient irrespective of distance from the target.

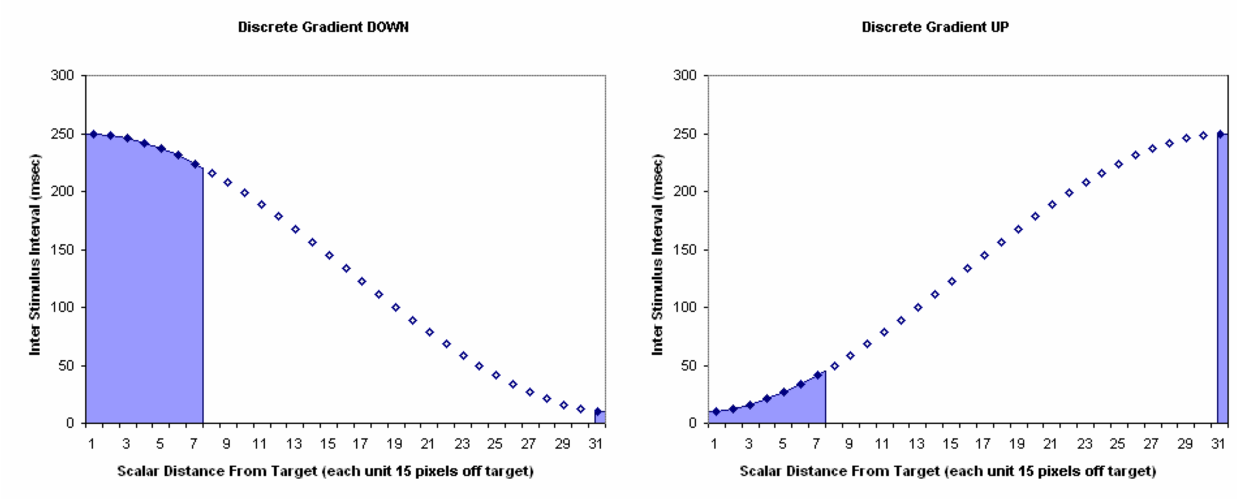


Figure 27: Discrete Inter Stimulus Interval x Scalar Distance from Target

A stimulus interval of 100 msec was applied to the tactile stimuli irrespective of the ISI. The gain was set such that all participants had a 100% detection rate for the tactile stimuli. White noise was presented via headphones to mask the sound of the mechanical relays used in the tactor driver.

Initial movement time (iMT), probability of correct initial movement (iMove), the number of times on-target (otCnt), time from target pop-up to target selection (ST), final time spent on-target (fTot), workload (WL), and time-stamped movement profiles were collected for each trial.

iMT for this experiment is defined as the time in seconds between target pop-up and the start of movement by the participant. iMT should be faster for the Visual + Tactile Display condition than Tactile-Only. We may use the initial pulse(s) as a simple direction and relative distance cue for planning the initial ballistic movement. When vibrotactile pulses are present, we can reduce the search space by half, reducing the search time by up to half.

iMove is the probability of a correct initial movement toward the target by the participant. iMove should not vary between conditions. The tactile display always indicates the direction to the target irrespective of the condition, so any variation between conditions will be attributable to error in this project.

otCnt is defined as the number of times the cursor went from off-target to on-target. otCnt should be at a minimum when the difference between on- and off-target is maximized (e.g., TarS/GraU, TarEf/GraDo).

ST is the time in seconds from target pop-up to target selection. As with otCnt, ST should be at a minimum when the difference between on- and off-target is maximized (e.g., TarS/GraU, TarEf/GraDo).

fTot is the time in seconds from the last time the participant moves from off- to on-target until the participant clicks on the target. fTot should be at a minimum when the difference between on- and off-target is maximized (e.g., TarS/GraU, TarEf/GraDo).

WL is the workload obtained from the NASA TLX. WL should be at a minimum when the difference between on- and off-target is maximized (e.g., TarS/GraU, TarEf/GraDo).

Movement profiles consisted of the time-stamped (in seconds) horizontal screen coordinate of the center of the cursor recorded every time the mouse position changed. A maximum recording rate of about 100 mouse movements per second was achieved for the described system.

The Edinburgh Handedness Inventory (EHI) (Oldfield, 1971) was used before participant training to collect the degree of handedness of each participant. The NASA-TLX workload assessment tool was used to measure perceived workload after each block of 32 trials.

Procedure

Throughout the course of the experiment the participants sat in front of the computer monitor in such a way that their mouse hand could comfortably move the mouse on the desk and the forearm was supported. The monitor was positioned approximately 21 inches from the bridge of the participant's nose.

The inertial mouse was positioned on the desk between the monitor and the participant on the participant's medial plane, and a computer-based version of the Edinburgh Handedness Inventory (EHI) was administered. The tactors were then applied to the participant's preferred hand for manipulating the mouse based on which hand the participant used to perform the EHI. The tactors were placed on the dorsal surface of the hand outside and in the middle of the second and fifth Metacarpals (see Figure 28). A fabric strap wrapped around the hand held the tactors in place.

Figure 28: Placement of tactors on dorsal surface of hand

A tactor discrimination test was administered before the start of the first block of trials, and again after the last block of trials. Participants were presented a randomized set of left, right, or both tactor stimuli and asked to select which tactors were activated. Each stimulus pulsed once with an SI of 100 msec. Each of the three tactor stimuli were presented 6 times, for a total of 18 trials. The “left” and “right” buttons for indicating the left and right tactors, respectively, were centered between the nearest and farthest target positions. The “both” button was positioned in the center of the screen. Upon completion of the 18 trials, the participants shifted a continuous scrollbar left or right to indicate the relative intensity of the left and right tactors. The gain of the tactors was kept constant throughout the experiment.

Training before the start of each block of 32 trials included a review of the stimuli that will be presented for the block, 8 training targets, and a post-training opportunity to ask questions about the stimuli. The training targets were presented with a random 2 to 9 second lag between target drop and target pop-up.

The primary task of the participants during a trial was to quickly move the cursor onto the target when they had an idea where the target is located, and clicking the left mouse button. When a trial begins, the target stimuli were presented as appropriate for the block. The stimuli continued to be presented until the trial ended. Each trial ended when the participant clicked on the target. The next trial began after a random delay ranging from 2 to 9 seconds.

Results

The GLM in SPSS 11.5 was employed to analyze the 2 x 3 x 2 x 2 mixed factorial design. Fisher’s LSD was employed on all simple main effects analyses. All tests were run at the $\alpha = .05$ level.

Correlations between participants' characteristics and the independent variables of interest reveal that Gender was significantly correlated with all of the variables of interest, and Age was significantly correlated with On-Target Count and Workload (see Appendix: Correlation Tables). As such, both characteristics were entered as covariates as appropriate in the GLM. Though the order of presentation of the Visual +Tactile and Tactile-only display modes was fully counterbalanced, the order was also entered as a covariate in the GLM to account for any order effect that may be present.

Initial Movement Time (iMT)

The results for iMT are presented in Table 11. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 12. Figure 29 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 13. Figure 30 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Figure 31 depicts the significant main effect of Display.

Table 11: Results for raw initial Movement Time (sec)

Source	SS	*df*	ms	*F*	*p*	η_p^2	*1-β*
Between Subjects							
Gender	0.010	1	0.010	0.270	ns	.010	.097
Visual First	0.012	1	0.012	0.325	ns	.012	.085
GraCDi	0.013	1	0.013	0.352	ns	.013	.088
GraUDo	0.008	1	0.008	0.225	ns	.009	.074
GraCDi x GraUDo	0.004	1	0.004	0.123	ns	.005	.063
Errorb	0.931	26	0.036				
Within Subjects							
Display	0.323	1	0.323	17.385	< .001	.401	.980
Display x Gender	0.028	1	0.028	1.496	ns	.054	.218
Display x Visual First	0.000	1	0.000	0.017	ns	.001	.052
Display x CraCDi	0.035	1	0.035	1.892	ns	.068	.263
Display x GraUDo	0.009	1	0.009	0.502	ns	.019	.105
Display x GraCDi x GraUDo	0.001	1	0.001	0.031	ns	.001	.053
Error(Display)	0.484	26	0.019				
TarSEsf	0.002	2	0.001	0.290	ns	.011	.094
TarSEsf x Gender	0.001	2	0.000	0.094	ns	.004	.064
TarSEsf x Visual First	0.001	2	0.000	0.107	ns	.004	.065
TarSEsf x GraCDi	0.001	2	0.000	0.119	ns	.005	.067
TarSEsf x GraUDo	0.008	2	0.004	0.985	ns	.037	.212
TarSEsf x GraCDi x GraUDo	0.001	2	0.000	0.123	ns	.005	.068
Error(TarSEsf**)**	0.210	52	0.004				
Display x TarSEsf	0.001	2	0.000	0.131	ns	.005	.069
Display x TarSEsf x Gender	0.004	2	0.002	0.611	ns	.023	.147
Display x TarSEsf x Visual First	0.003	2	0.001	0.487	ns	.018	.126
Display x TarSEsf x GraCDi	0.003	2	0.002	0.550	ns	.021	.136
Display x TarSEsf x GraUDo	0.013	2	0.007	2.162	ns	.077	.423
Display x TarSEsf x GraCDi x GraUDo	0.013	2	0.006	2.114	ns	.075	.415
Errorw	0.159	52	0.003				

Table 12: Means for Display x TarSEsf x GraCDi x GraUDo on iMT

	Vis+Tac/TarS	Vis+Tac/TarEf	Vis+Tac/TarEs	Tac/TarS	Tac/TarEf	Tac/TarEs
GraC/GraU	0.3343	0.3319	0.3622	0.4764	0.5110	0.5112
GraC/GraDo	0.3366	0.3695	0.3342	0.5182	0.4805	0.5319
GraDi/GraU	0.3573	0.3436	0.3582	0.4133	0.4432	0.4674
GraDi/GraDo	0.3510	0.3539	0.3532	0.4931	0.4874	0.4688

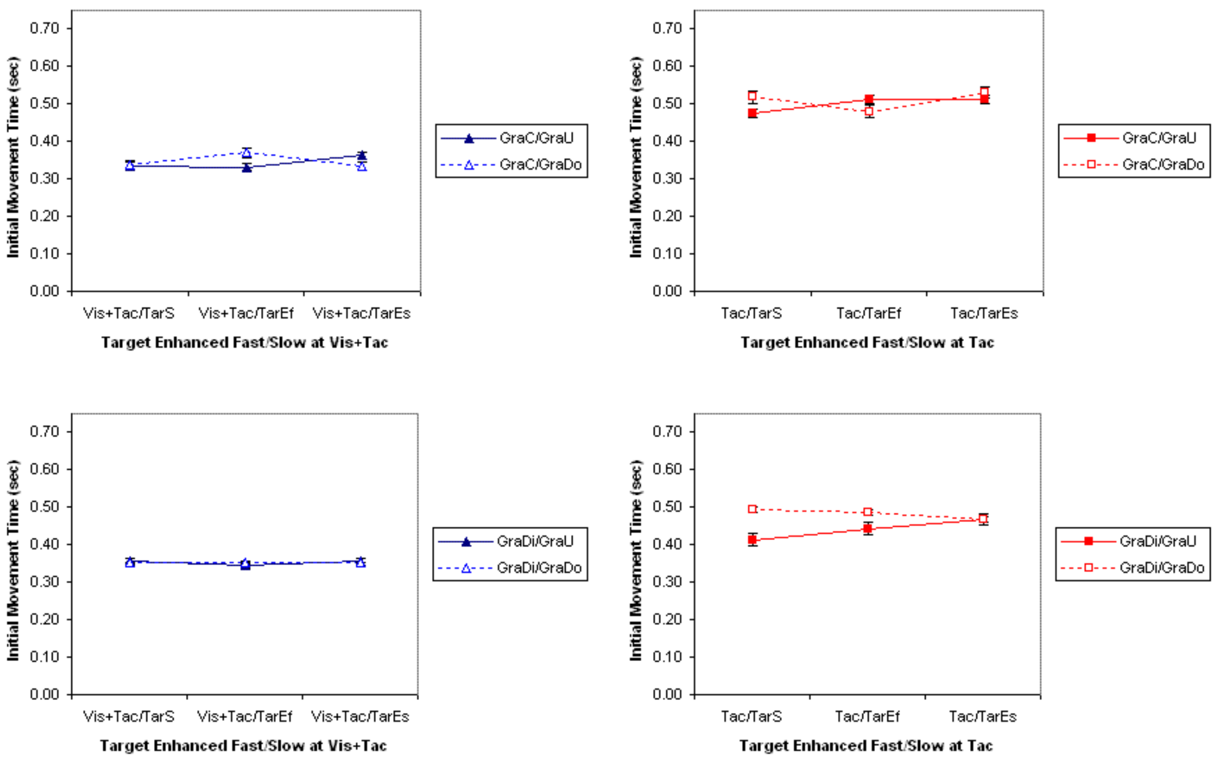
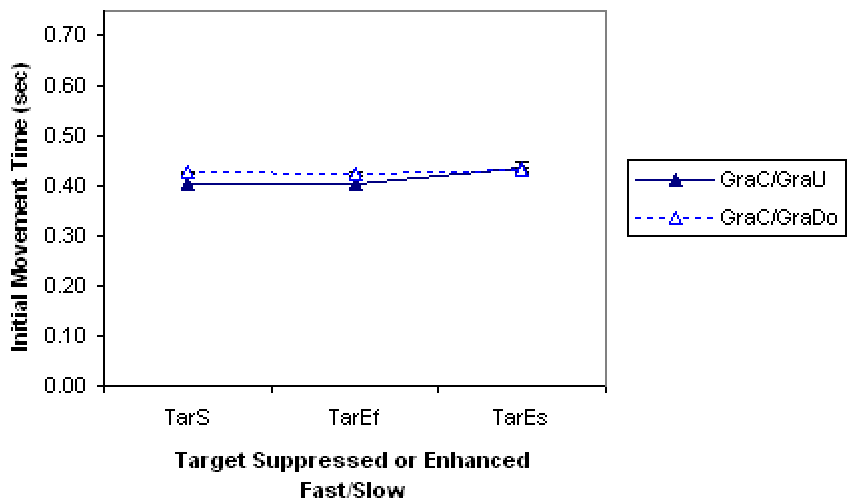


Figure 29: Display x TarSEsf x GraCDi x GraUDo on iMT

Table 13: Means for TarSEsf x GraCDi x GraUDo on iMT

	TarS	TarEf	TarEs
GraC/GraU	0.4054	0.4042	0.4367
GraC/GraDo	0.4274	0.4250	0.4331
GraDi/GraU	0.3853	0.3934	0.4128
GraDi/GraDo	0.4221	0.4207	0.4110



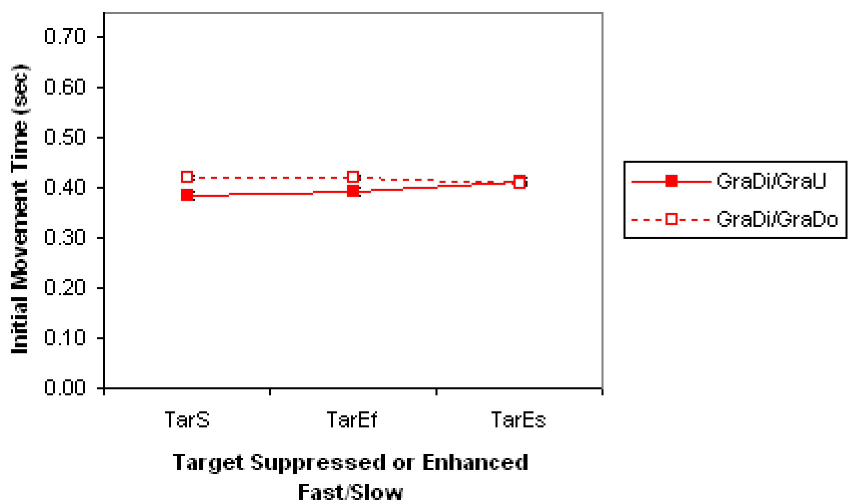


Figure 30: TarSEsf x GraCDi x GraUDo on iMT

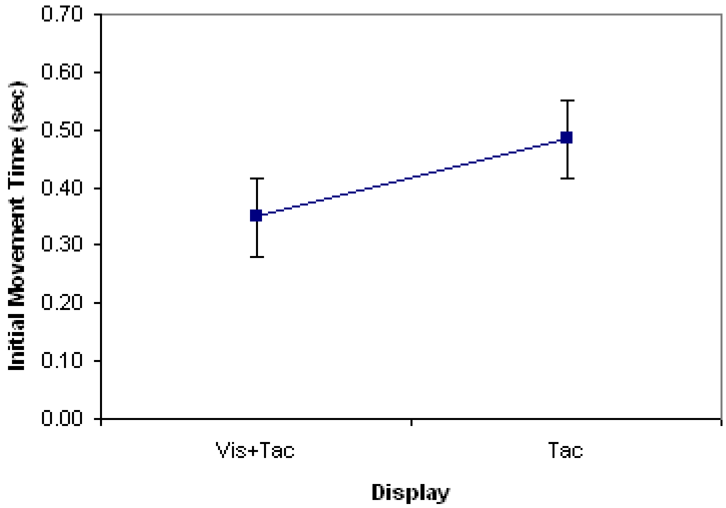


Figure 31: Display on iMT

The Tactile-Only display condition resulted in slower initial movement times than Visual + Tactile. No other main effects were significant. No interactions were significant.

Selection Time (ST)

The results for ST are presented in Table 14. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 15. Figure 32 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 16. Figure 33 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Means for the significant Display x TarSEsf x GarUDo interaction are presented in Table 17. Figure 34 depicts the significant Display x TarSEsf x GraUDo interaction. Means for the significant TarSEsf x GraUDo interaction are presented in Table 18. Figure 35 depicts the significant TarSEsf x GraUDo interaction. Figure 36 depicts the significant main effect of Display.

Table 14: Results for Target Selection Time (sec)

Source	SS	*df*	ms	*F*	*p*	η_p^2	*1-β*
Between Subjects							
Gender	25.896	1	25.896	10.626	.003	.290	.880
Visual First	0.042	1	0.042	0.017	ns	.001	.052
GraCDi	4.486	1	4.486	1.841	ns	.066	.257
GraUDo	4.042	1	4.042	1.659	ns	.060	.237
GraCDi x GraUDo	0.011	1	0.011	0.005	ns	.000	.050
Errorb	63.364	26	2.437				
Within Subjects							
Display	416.244	1	416.244	174.830	< .001	.871	1.000
Display x Gender	14.093	1	14.093	5.919	.022	.185	.649
Display x Visual First	0.058	1	0.058	0.024	ns	.001	.053
Display x CraCDi	2.028	1	2.028	0.852	ns	.032	.144
Display x GraUDo	6.734	1	6.734	2.828	ns	.098	.367
Display x GraCDi x GraUDo	0.217	1	0.217	0.091	ns	.003	.060
Error(Display)	61.902	26	2.381				
TarSEsf	1.654	2	0.827	0.718	ns	.027	.165
TarSEsf x Gender	4.513	2	2.257	1.958	ns	.070	.387
TarSEsf x Visual First	.600	2	0.300	0.260	ns	.010	.089
TarSEsf x GraCDi	4.893	2	2.446	2.122	ns	.075	.416
TarSEsf x GraUDo	8.248	2	4.124	3.578	.035	.121	.639
TarSEsf x GraCDi x GraUDo	1.638	2	0.819	0.710	ns	.027	.164
Error(TarSEsf**)**	59.943	52	1.153				
Display x TarSEsf	1.727	2	0.864	0.695	ns	.026	.161
Display x TarSEsf x Gender	3.707	2	1.854	1.492	ns	.054	.304
Display x TarSEsf x Visual First	0.701	2	0.350	0.282	ns	.011	.092
Display x TarSEsf x GraCDi	4.928	2	2.464	1.983	ns	.071	.392
Display x TarSEsf x GraUDo	8.317	2	4.159	3.347	.043	.114	.608
Display x TarSEsf x GraCDi x GraUDo	1.870	2	0.935	0.752	ns	.028	.171
Errorw	64.604	52	1.242				

Table 15: Means for Display x TarSEsf x GraCDi x GraUDo on ST

	Vis+Tac/TarS	Vis+Tac/TarEf	Vis+Tac/TarEs	Tac/TarS	Tac/TarEf	Tac/TarEs
GraC/GraU	1.3675	1.3993	1.4102	4.2978	5.4173	4.0581
GraC/GraDo	1.3243	1.2982	1.3105	5.8907	5.4279	5.8280
GraDi/GraU	1.4718	1.4561	1.4756	5.2027	5.4432	5.4790
GraDi/GraDo	1.4091	1.4290	1.3866	6.9126	4.5726	5.8255

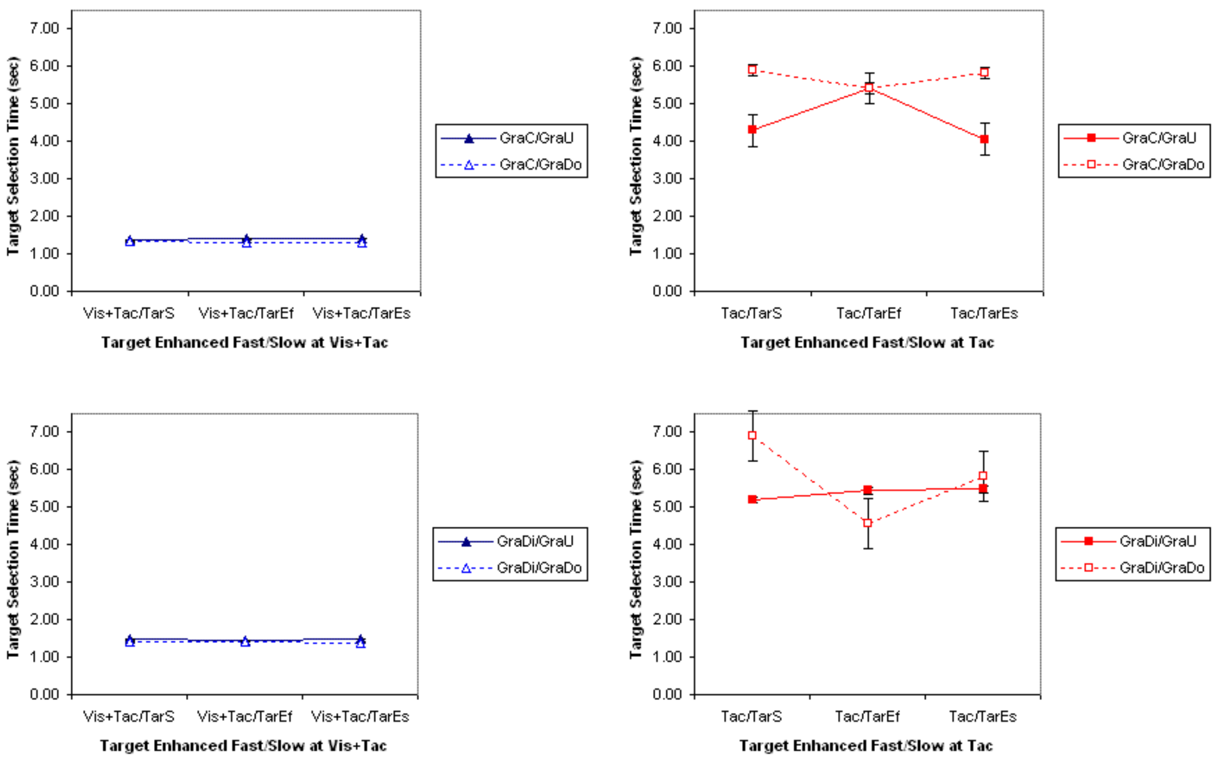
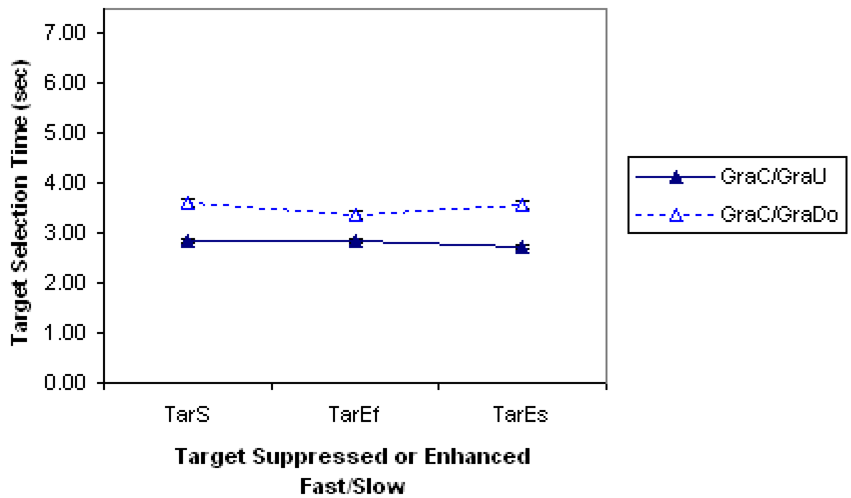


Figure 32: Display x TarSEsf x GraCDi x GarUDo on ST

Table 16: Means for TarSEsf x GraCDi x GraUDo on ST

	TarS	TarEf	TarEs
GraC/GraU	2.8326	2.8486	2.7342
GraC/GraDo	3.6075	3.3631	3.5692
GraDi/GraU	3.3373	3.4496	3.4773
GraDi/GraDo	4.1608	3.0008	3.6061



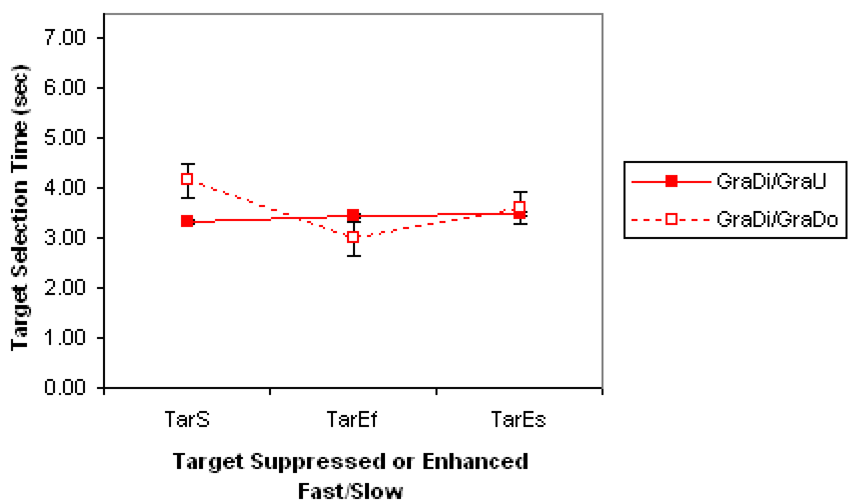


Figure 33: TarSEsf x GraCDi x GraUDo on ST

Table 17: Means for Display x TarSEsf x GarUDo on ST

	Vis+Tac/TarS	Vis+Tac/TarEf	Vis+Tac/TarEs	Tac/TarS	Tac/TarEf	Tac/TarEs
GraU	1.4197	1.4277	1.4429	4.7503	5.4303	4.7685
GraDo	1.3667	1.3636	1.3485	6.4016	5.0002	5.8268

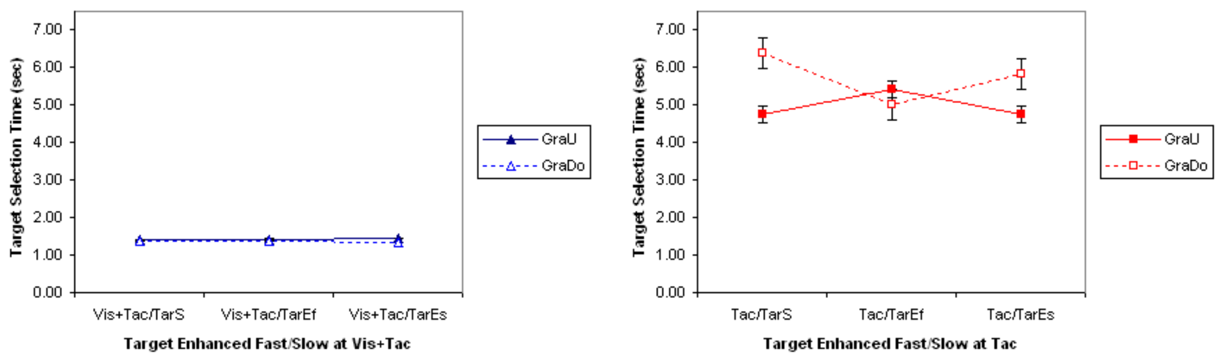


Figure 34: Display x TarSEsf x GarUDo on ST

Table 18: Means for TarSEsf x GraUDo on ST

	TarS	**TarEf**	**TarEs**
GraU	3.0850	3.4290	3.1057
GraDo	3.8842	3.1819	3.5876

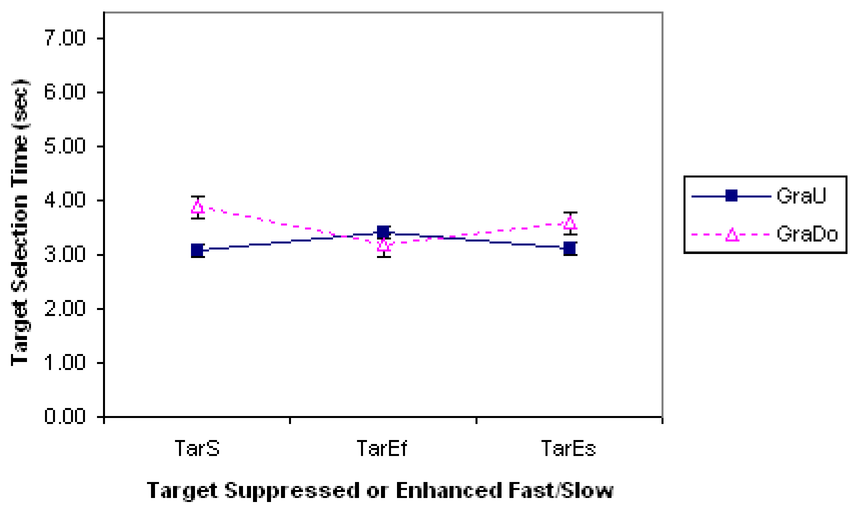


Figure 35: TarSEsf x GraUDo on ST

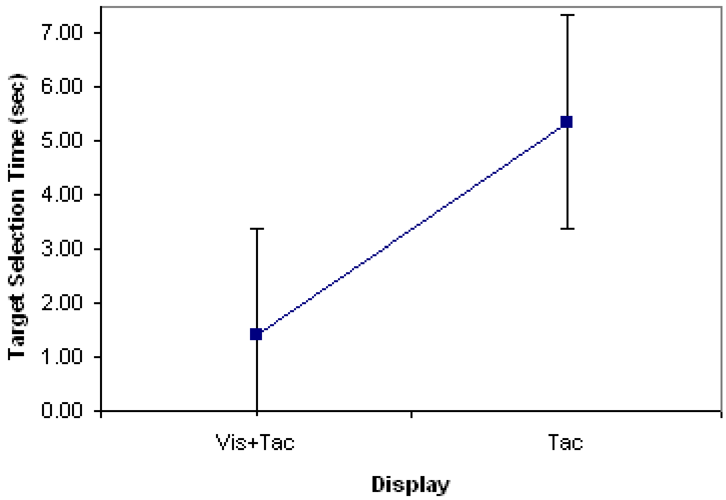


Figure 36: Display on ST

The Tactile-Only display condition resulted in slower target selection times than Visual + Tactile. No other main effects were significant.

For both the Display x TarSEsf x GarUDo and TarSEsf x GraUDo interactions, the GraDo condition resulted in slower target selection times than GraU at Tac/TarS and Tac/TarEs. The GraDo condition at TarS was slower than GraDo at TarEf.

On-Target Count (otCnt)

The results for otCnt are presented in Table 19. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 20. Figure 37 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 21. Figure 38 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Figure 39 depicts TarSEsf. Figure 40 depicts the non-significant main effect of Display.

Table 19: Results for On-Target Count

Source	SS	*df*	ms	*F*	*p*	η_p^2	*1-β*
Between Subjects							
Age	4.829	1	4.829	5.086	.033	.169	.582
Gender	0.297	1	0.297	0.312	ns	.012	.084
Visual First	1.915	1	1.915	2.016	ns	.075	.277
GraCDi	2.840	1	2.840	2.991	ns (.096)	.107	.383
GraUDo	0.714	1	0.714	0.752	ns	.029	.133
GraCDi x GraUDo	0.025	1	0.025	0.026	ns	.001	.053
Errorb	23.736	25	0.949				
Within Subjects							
Display	0.025	1	0.025	0.045	ns	.002	.055
Display x Age	4.534	1	4.534	8.254	.008	.248	.788
Display x Gender	0.018	1	0.018	0.033	ns	.001	.053
Display x Visual First	0.715	1	0.715	1.302	ns	.050	.195
Display x CraCDi	2.040	1	2.040	3.713	ns (.065)	.129	.457
Display x GraUDo	0.279	1	0.279	0.509	ns	.020	.105
Display x GraCDi x GraUDo	0.089	1	0.089	0.162	ns	.006	.067
Error(Display)	13.734	25	0.549				
TarSEsf	1.147	2	0.574	3.813	.029	.132	.667
TarSEsf x Age	2.238	2	1.119	7.436	.001	.229	.928
TarSEsf x Gender	0.384	2	0.192	1.276	ns	.049	.264
TarSEsf x Visual First	0.284	2	0.142	0.944	ns	.036	.204
TarSEsf x GraCDi	0.318	2	0.159	1.057	ns	.041	.225
TarSEsf x GraUDo	0.440	2	0.220	1.462	ns	.055	.298
TarSEsf x GraCDi x GraUDo	0.004	2	0.002	0.014	ns	.001	.052
Error(TarSEsf**)**	7.523	50	0.150				
Display x TarSEsf	0.730	2	0.365	2.272	ns	.083	.441
Display x TarSEsf x Age	1.464	2	0.732	4.552	.015	.154	.749
Display x TarSEsf x Gender	0.610	2	0.305	1.898	ns	.071	.376
Display x TarSEsf x Visual First	0.526	2	0.263	1.637	ns	.061	.330
Display x TarSEsf x GraCDi	0.388	2	0.194	1.207	ns	.046	.252
Display x TarSEsf x GraUDo	0.162	2	0.081	0.503	ns	.020	.128
Display x TarSEsf x GraCDi x GraUDo	0.040	2	0.020	0.124	ns	.005	.068
Errorw	8.038	50	0.161				

Table 20: Means for Display x TarSEsf x GraCDi x GraUDo on otCnt

	Vis+Tac/TarS	Vis+Tac/TarEf	Vis+Tac/TarEs	Tac/TarS	Tac/TarEf	Tac/TarEs
GraC/GraU	1.3672	1.3750	1.2969	2.8672	2.5313	2.1875
GraC/GraDo	1.3984	1.2969	1.3516	2.6016	2.4063	2.5391
GraDi/GraU	1.3438	1.3594	1.3438	3.0156	2.6719	2.6250
GraDi/GraDo	1.4297	1.4141	1.4375	3.2656	2.6406	2.9375

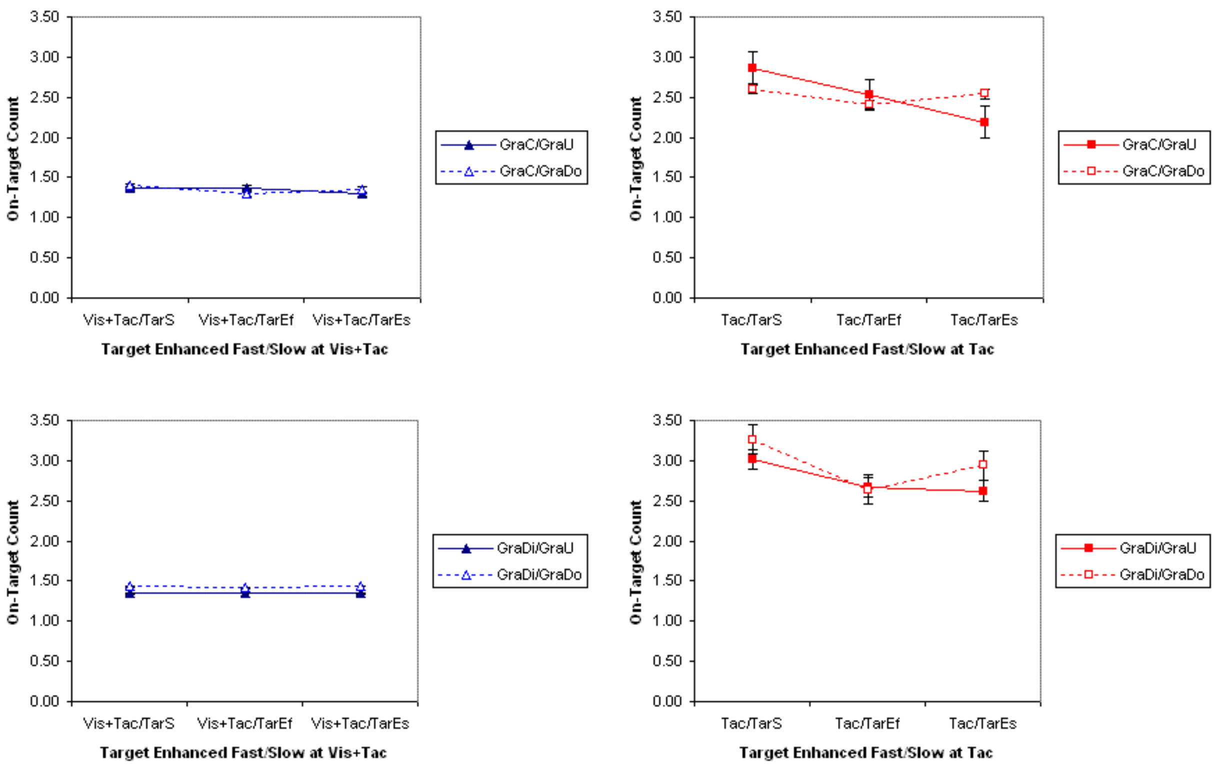
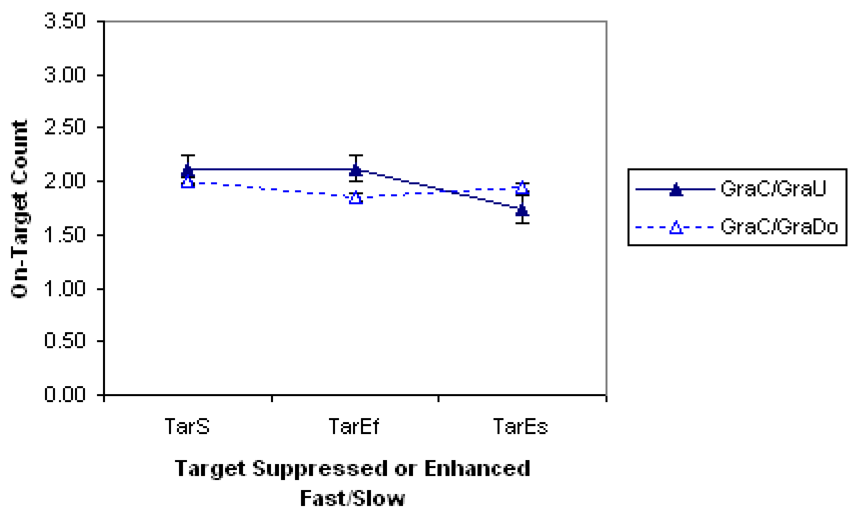


Figure 37: Display x TarSEsf x GraCDi x GarUDo on otCnt

Table 21: Means for TarSEsf x GraCDi x GraUDo on otCnt

	TarS	TarEf	TarEs
GraC/GraU	2.1172	2.1211	1.7422
GraC/GraDo	2.0000	1.8516	1.9453
GraDi/GraU	2.1797	2.0156	1.9844
GraDi/GraDo	2.3477	2.0273	2.1875



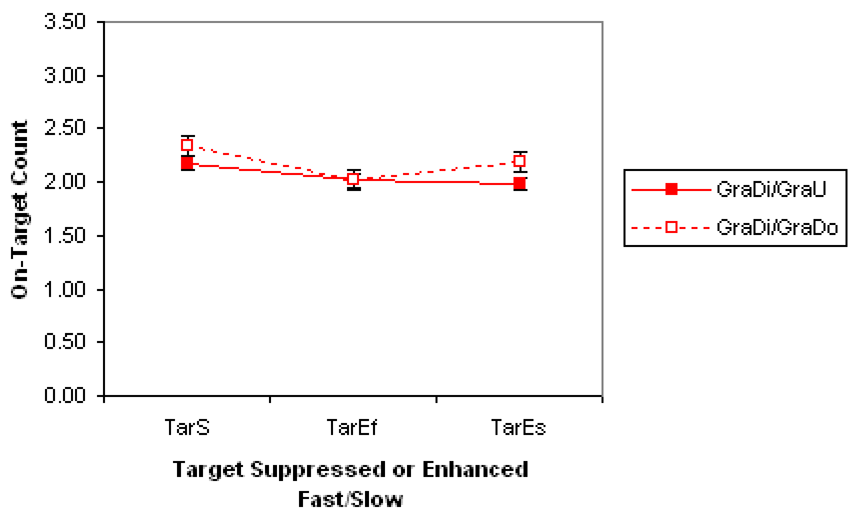


Figure 38: TarSEsf x GraCDi x GarUDo on otCnt

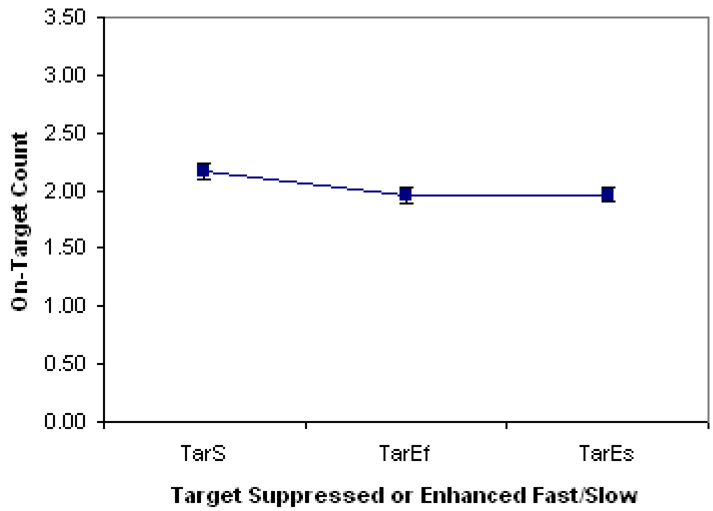


Figure 39: TarSEsf on otCnt

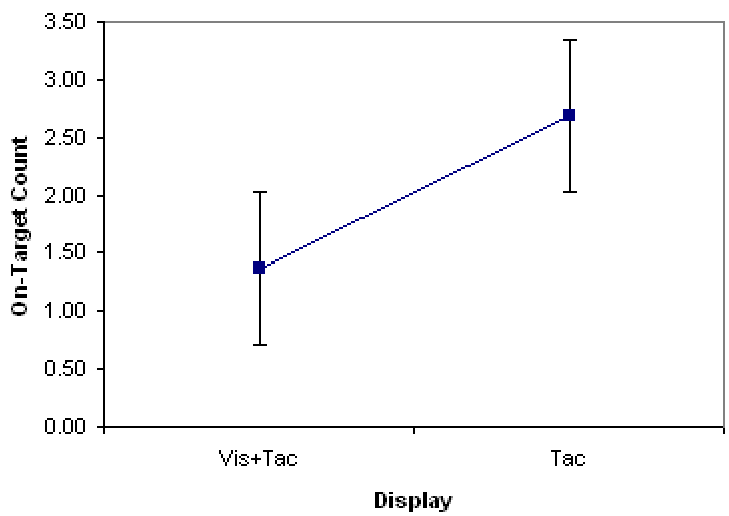


Figure 40: Display on otCnt

Investigating the significant TarSEsf main effect, TarS had more movements from Off- to On-Target than did TarEf or TarEs. TarEf and TarEs were not found to be significantly different. No other main effects were significant. No interaction effects were significant.

Probability of Correct Initial Movement (iMove)

The results for iMove are presented in Table 22. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 23. Figure 41 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 24. Figure 42 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Figure 43 depicts the non-significant main effect of Display.

Table 22: Results for Probability of Correct Initial Movement

Source	SS	*df*	ms	*F*	*p*	η_p^2	$1\text{-}\beta$
Between Subjects							
Gender	0.060	1	0.060	2.642	ns	.092	.347
Visual First	0.011	1	0.011	0.493	ns	.019	.104
GraCDi	0.083	1	0.083	3.634	ns (.068)	.123	.451
GraUDo	0.014	1	0.014	0.599	ns	.023	.116
GraCDi x GraUDo	0.015	1	0.015	0.671	ns	.025	.124
Errorb	0.593	26	0.023				
Within Subjects							
Display	0.002	1	0.002	0.103	ns	.004	.061
Display x Gender	0.012	1	0.012	0.832	ns	.031	.142
Display x Visual First	0.022	1	0.022	1.465	ns	.053	.215
Display x CraCDi	0.004	1	0.004	0.261	ns	.010	.078
Display x GraUDo	0.003	1	0.003	0.204	ns	.008	.072
Display x GraCDi x GraUDo	0.002	1	0.002	0.148	ns	.006	.066
Error(Display)	0.384	26	0.015				
TarSEsf	0.000	2	0.000	0.009	ns	.000	.051
TarSEsf x Gender	0.030	2	0.015	1.745	ns	.063	.350
TarSEsf x Visual First	0.011	2	0.006	0.635	ns	.024	.151
TarSEsf x GraCDi	0.025	2	0.012	1.413	ns	.052	.290
TarSEsf x GraUDo	0.010	2	0.005	0.598	ns	.022	.144
TarSEsf x GraCDi x GraUDo	0.004	2	0.002	0.221	ns	.008	.083
Error(TarSEsf**)**	0.453	52	0.009				
Display x TarSEsf	0.037	2	0.019	2.606	ns (.083)	.091	.497
Display x TarSEsf x Gender	0.001	2	0.001	0.103	ns	.004	.065
Display x TarSEsf x Visual First	0.018	2	0.009	1.236	ns	.045	.258
Display x TarSEsf x GraCDi	0.007	2	0.004	0.508	ns	.019	.129
Display x TarSEsf x GraUDo	0.006	2	0.003	0.422	ns	.016	.115
Display x TarSEsf x GraCDi x GraUDo	0.014	2	0.007	0.965	ns	.036	.209
Errorw	0.370	52	0.007				

Table 23: Means for Display x TarSEsf x GraCDi x GraUDo on iMove

	Vis+Tac/TarS	Vis+Tac/TarEf	Vis+Tac/TarEs	Tac/TarS	Tac/TarEf	Tac/TarEs
GraC/GraU	0.9375	0.8672	0.9375	0.9219	0.9141	0.9297
GraC/GraDo	0.9453	0.9219	0.8984	0.8906	0.8672	0.9141
GraDi/GraU	0.8828	0.8516	0.8672	0.7891	0.8672	0.8594
GraDi/GraDo	0.9141	0.9063	0.8984	0.8594	0.9219	0.8594

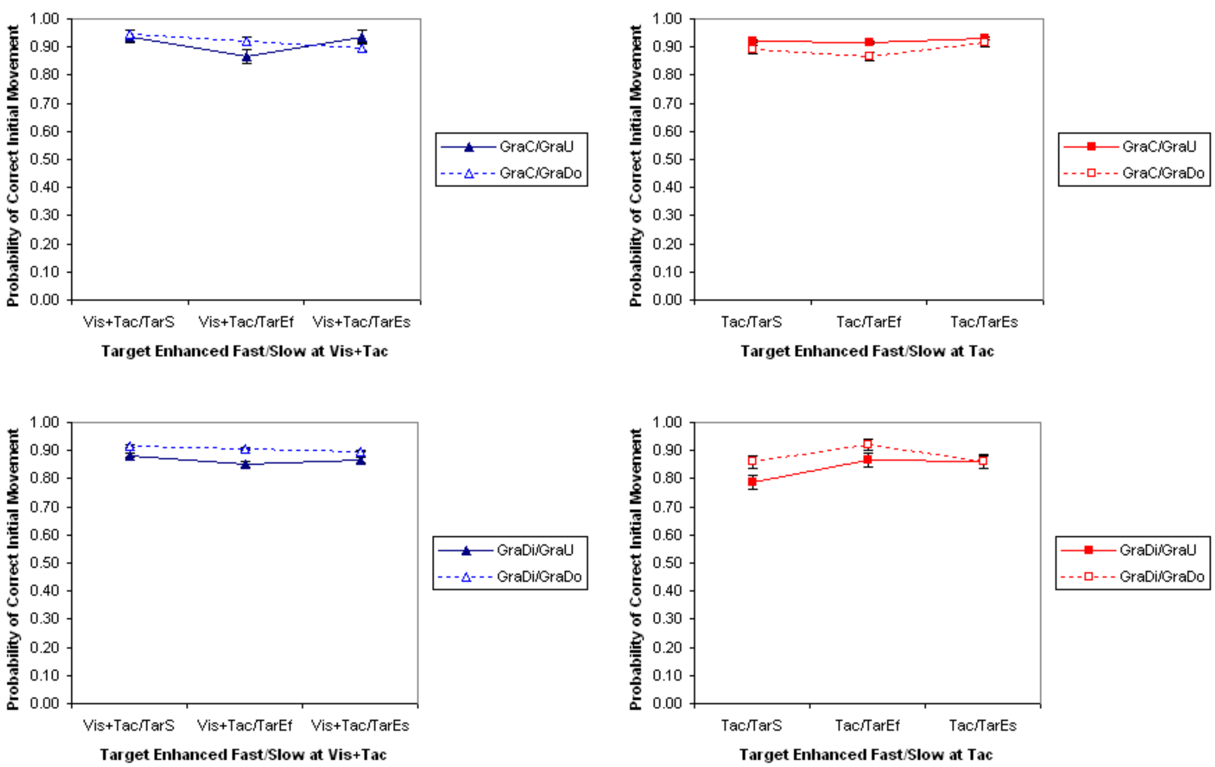


Figure 41 Display x TarSEsf x GraCDi x GarUDo on iMove

Table 24 Means for TarSEsf x GraCDi x GraUDo on iMove

	TarS	TarEf	TarEs
GraC/GraU	0.9297	0.8945	0.9336
GraC/GraDo	0.9180	0.8945	0.9063
GraDi/GraU	0.8359	0.8594	0.8633
GraDi/GraDo	0.8867	0.9141	0.8789

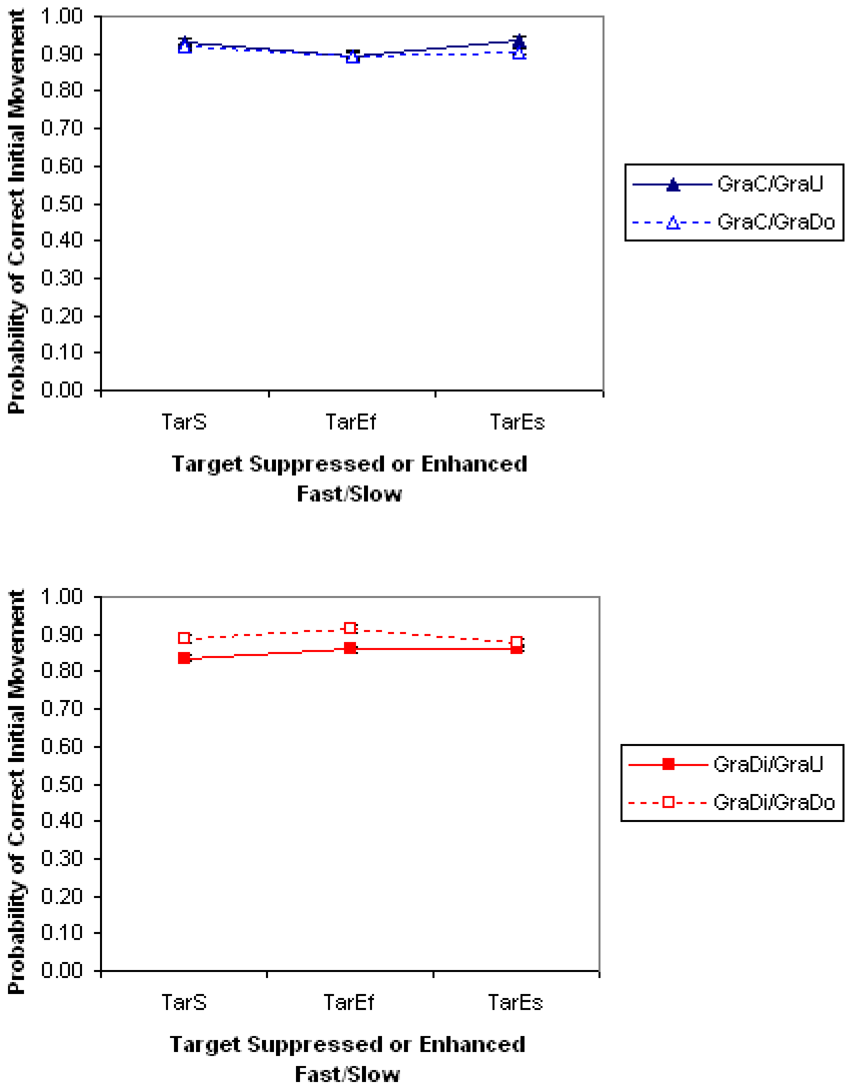


Figure 42: TarSEsf x GraCDi x GarUDo on iMove

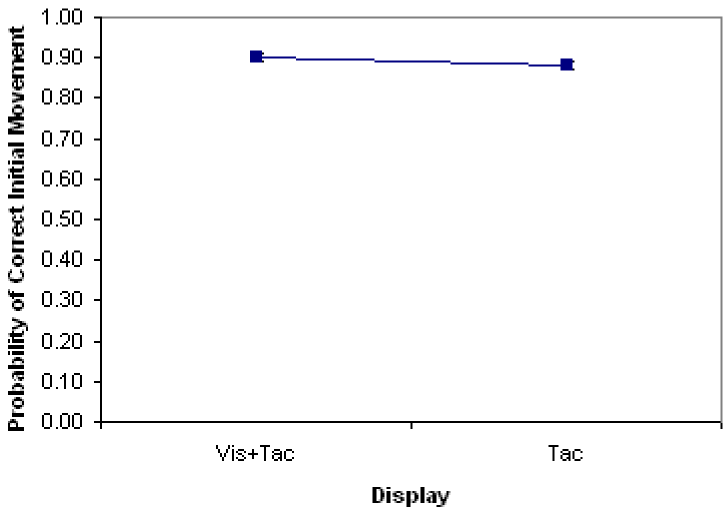


Figure 43: Display on iMove

No significant main effects were found. No significant interaction effects were found.

Final Time On-Target (fTot)

The results for fTot are presented in Table 25. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 26. Figure 44 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 27. Figure 45 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Means for the significant Display x TarSEsf x GraUDo interaction are presented in Table 28. Figure 46 depicts the significant Display x TarSEsf x GraUDo interaction. Means for the significant Display x TarSEsf interaction are presented in Table 29. Figure 47 depicts the significant Display x TarSEsf interaction. Means for the significant TarSEsf x GraUDo interaction are presented in Table 30.

Figure 48 depicts the significant TarSEsf x GraUDo interaction. Means for the significant TarSEsf x GraCDi interaction are presented in Table 31. Figure 49 depicts the significant TarSEsf x GraCDi interaction. Figure 50 depicts the significant main effect of TarSEsf. Figure 51 depicts the significant main effect of Display.

Table 25: Results for Final Time On-Target

Source	SS	*df*	ms	*F*	*p*	η_p^2	*1-β*
Between Subjects							
Gender	0.770	1	0.770	9.261	.005	.263	.834
Visual First	0.012	1	0.012	0.141	ns	.005	.065
GraCDi	0.182	1	0.182	2.188	ns	.078	.297
GraUDo	0.117	1	0.117	1.404	ns	.051	.207
GraCDi x GraUDo	0.292	1	0.292	3.508	ns (.072)	.119	.438
Errorb	2.161	26	0.083				
Within Subjects							
Display	5.920	1	5.920	122.800	< .001	.825	1.000
Display x Gender	0.095	1	0.095	1.972	ns	.070	.272
Display x Visual First	0.037	1	0.037	0.761	ns	.028	.134
Display x CraCDi	0.005	1	0.005	0.102	ns	.004	.061
Display x GraUDo	0.146	1	0.146	3.036	ns (.093)	.105	.389
Display x GraCDi x GraUDo	0.026	1	0.026	0.541	ns	.020	.109
Error(Display)	1.253	26	0.048				
TarSEsf	0.084	2	0.042	4.854	.012	.157	.778
TarSEsf x Gender	0.045	2	0.023	2.602	ns (.084)	.091	.496
TarSEsf x Visual First	0.051	2	0.025	2.913	ns (.063)	.101	.545
TarSEsf x GraCDi	0.064	2	0.032	3.684	.032	.124	.652
TarSEsf x GraUDo	0.223	2	0.111	12.833	< .001	.330	.996
TarSEsf x GraCDi x GraUDo	0.007	2	0.003	0.396	ns	.015	.111
Error(TarSEsf**)**	0.451	52	0.009				
Display x TarSEsf	0.080	2	0.040	4.223	.020	.140	.716
Display x TarSEsf x Gender	0.009	2	0.005	0.481	ns	.018	.125
Display x TarSEsf x Visual First	0.067	2	0.033	3.515	.037	.119	.630
Display x TarSEsf x GraCDi	0.057	2	0.029	3.017	ns (.058)	.104	.560
Display x TarSEsf x GraUDo	0.185	2	0.093	9.753	< .001	.273	.977
Display x TarSEsf x GraCDi x GraUDo	0.011	2	0.005	0.571	ns	.022	.140
Errorw	0.494	52	0.010				

Table 26: Means for Display x TarSEsf x GraCDi x GraUDo on fTot

	Vis+Tac/TarS	Vis+Tac/TarEf	Vis+Tac/TarEs	Tac/TarS	Tac/TarEf	Tac/TarEs
GraC/GraU	0.3732	0.3884	0.3899	0.6155	0.9062	0.8629
GraC/GraDo	0.3609	0.3449	0.3323	0.8310	0.7331	0.9740
GraDi/GraU	0.3863	0.3940	0.3941	0.6976	0.7575	0.9092
GraDi/GraDo	0.4473	0.4303	0.4108	0.9811	0.8067	1.1267

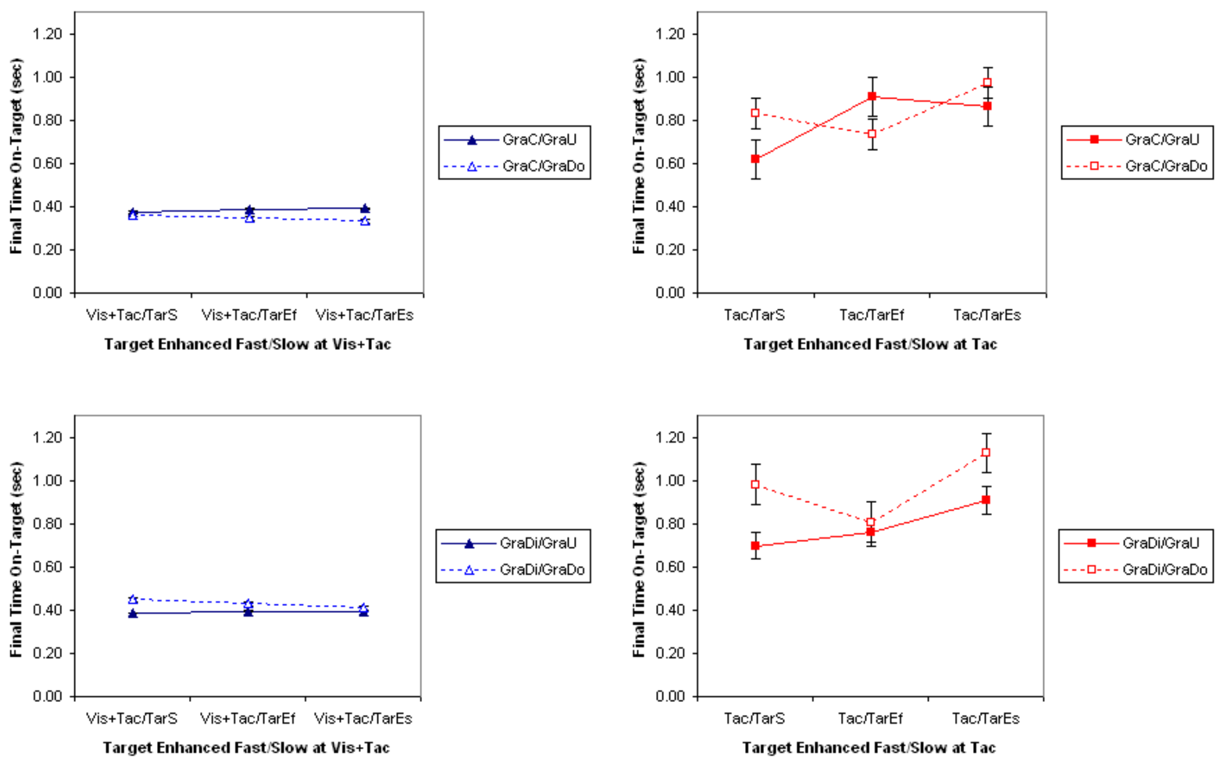
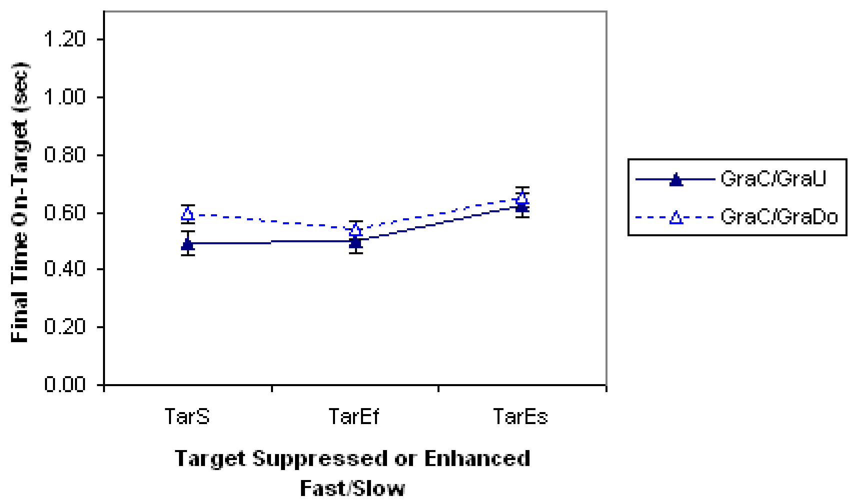


Figure 44: Display x TarSEsf x GraCDi x GarUDo on fTot

Table 27: Means for TarSEsf x GraCDi x GraUDo on fTot

	TarS	TarEf	TarEs
GraC/GraU	0.4943	0.5020	0.6264
GraC/GraDo	0.5960	0.5390	0.6531
GraDi/GraU	0.5419	0.5758	0.6516
GraDi/GraDo	0.7142	0.6185	0.7687



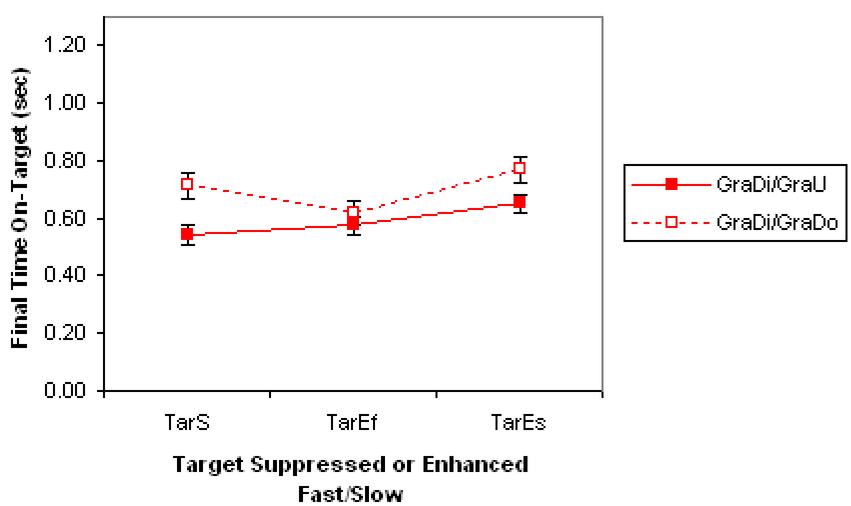


Figure 45: TarSEsf x GraCDi x GraUDo on fTot

Table 28: Means for Display x TarSEsf x GraUDo on fTot

	Vis+Tac/TarS	Vis+Tac/TarEf	Vis+Tac/TarEs	Tac/TarS	Tac/TarEf	Tac/TarEs
GraU	0.3798	0.3912	0.3920	0.6565	0.8318	0.8860
GraDo	0.4041	0.3876	0.3715	0.9061	0.7699	1.0503

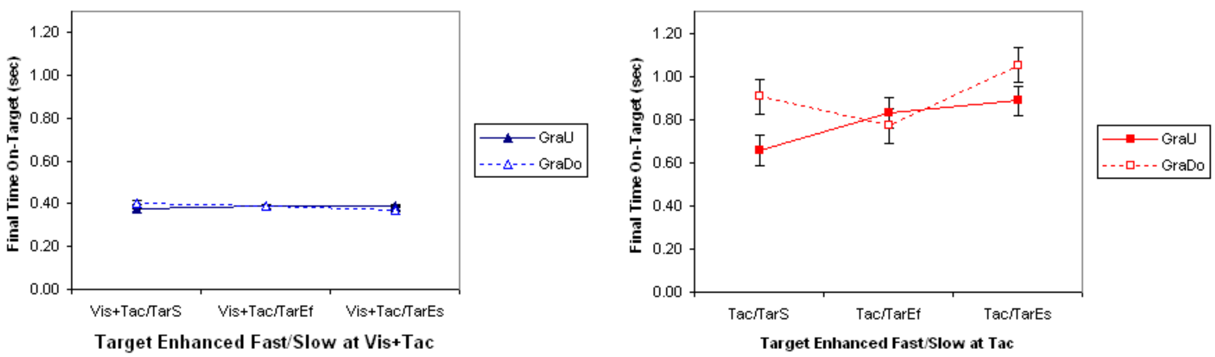


Figure 46: Display x TarSEsf x GraUDo on fTot

Table 29: Means for Display x TarSEsf on fTot

	TarS	TarEf	TarEs
Vis+Tac	0.3919	0.3894	0.3818
Tac	0.7813	0.8009	0.9682

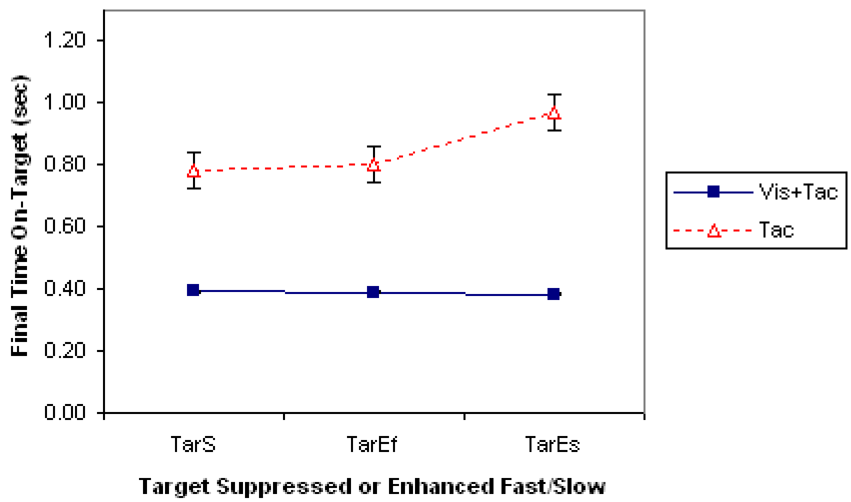


Figure 47: Display x TarSEsf on fTot

Table 30: Means for TarSEsf x GraUDo on fTot

	TarS	TarEf	TarEs
GraU	0.5181	0.6115	0.6390
GraDo	0.6551	0.5787	0.7109

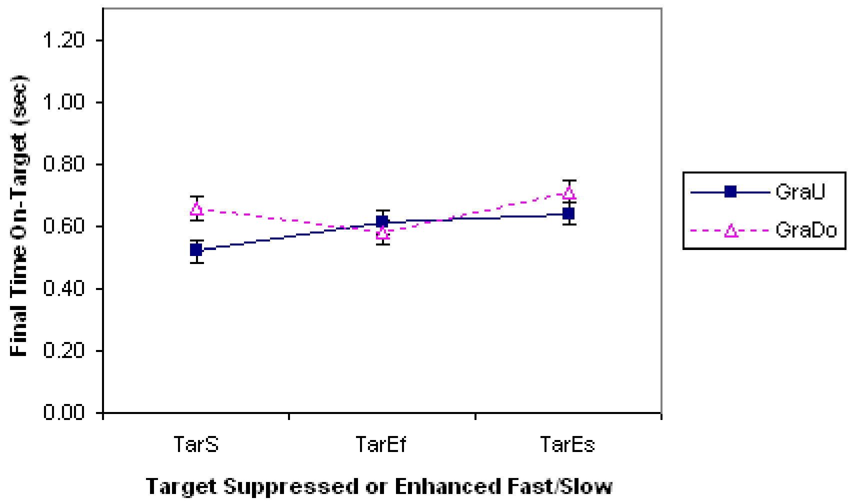


Figure 48: TarSEsf x GraUDo on fTot

Table 31: Means for TarSEsf x GraCDi on fTot

	TarS	**TarEf**	**TarEs**
GraC	0.5451	0.5931	0.6398
GraDi	0.6281	0.5971	0.7102

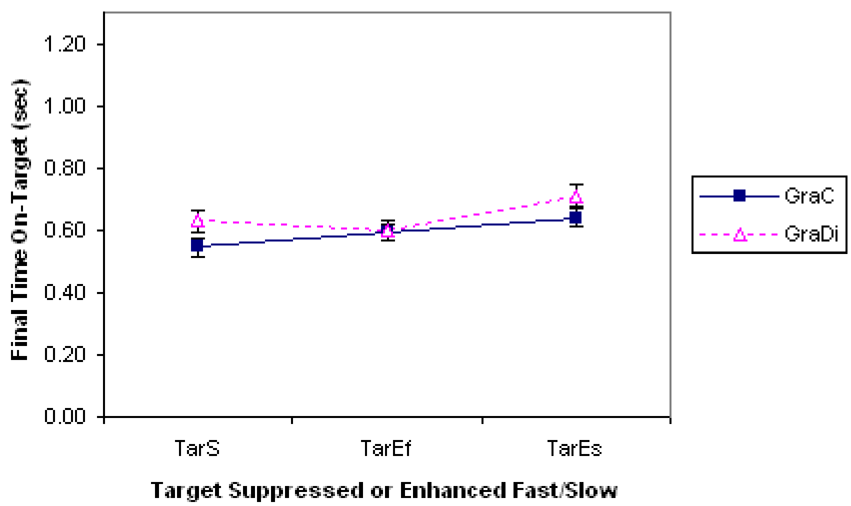


Figure 49: TarSEsf x GraCDi on fTot

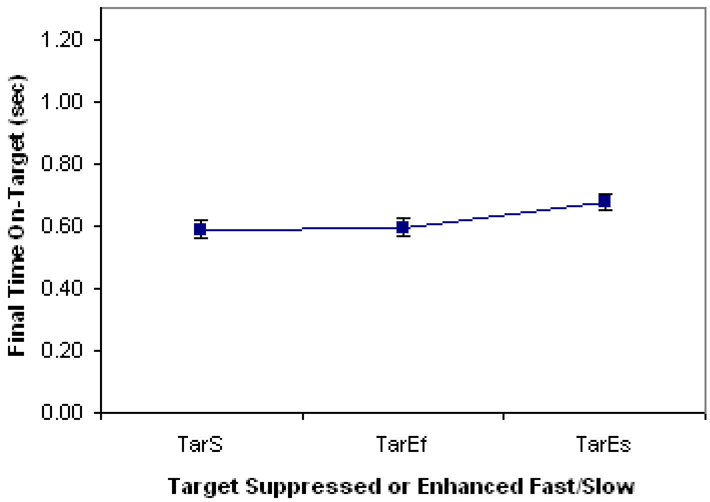


Figure 50: TarSEsf on fTot

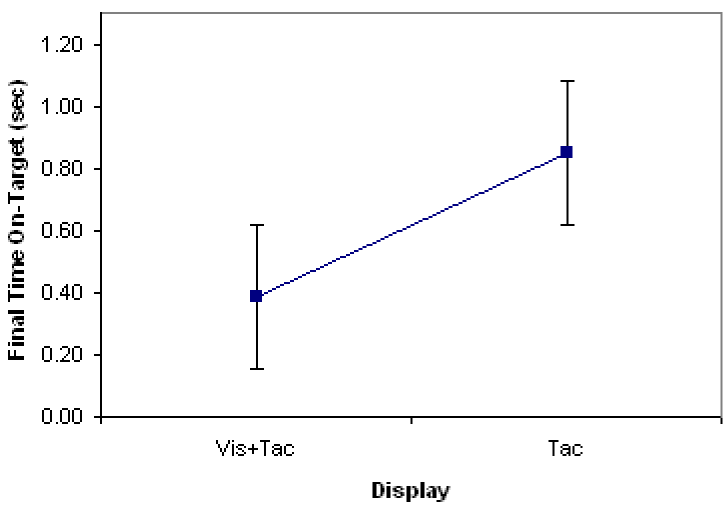


Figure 51: Display on fTot

The Tac display condition resulted in longer time on-target than Vis+Tac. The TarEs condition resulted in longer time on-target than TarS or TarEf. No other main effects were found.

GraU at Tac/TarS had shorter time on-target than all other Tac conditions. GraU at Tac/TarEs had shorter time on-target than GraDo at Tac/TarEs. GraDo at Tac/TarEf had shorter time on-target than at Tac/TarS and Tac/TarEs, and shorter time on-target than GraU at Tac/TarEs. GraDo at Tac/TarS had shorter time on-target than GraDo at Tac/TarEs.

GraDi at TarEs had longer times on-target than all other TarSEsf conditions. GraDi at TarS had longer times on-target than GraC at TarS. GraC at TarS had shorter times on-target than GraC at TarEs

Workload (WL)

The results for WL are presented in Table 32. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 33. Figure 52 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 34. Figure 53 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Means for the significant Display x TarSEsf x GraUDo interaction are presented in Table 35. Figure 54 depicts the significant Display x TarSEsf x GraUDo interaction. Figure 55 depicts the significant main effect of Display.

Table 32: Results for Workload

Source	SS	*df*	ms	*F*	*p*	η_p^2	$1\text{-}\beta$
Between Subjects							
Age	3188.481	1	3188.481	2.016	ns	.075	.277
Gender	134.080	1	134.080	0.085	ns	.003	.059
Visual First	4645.440	1	4645.440	2.938	ns (.099)	.105	.378
GraCDi	207.415	1	207.415	0.131	ns	.005	.064
GraUDo	3021.520	1	3021.520	1.911	ns	.071	.265
GraCDi x GraUDo	5523.705	1	5523.705	3.493	ns (.073)	.123	.435
Errorb	39534.500	25	1581.380				
Within Subjects							
Display	1151.375	1	1151.375	5.491	.027	.180	.615
Display x Age	216.961	1	216.961	1.035	ns	.040	.165
Display x Gender	35.433	1	35.433	0.169	ns	.007	.068
Display x Visual First	58.052	1	58.052	0.277	ns	.011	.080
Display x CraCDi	189.175	1	189.175	0.902	ns	.035	.150
Display x GraUDo	110.489	1	110.489	0.527	ns	.021	.107
Display x GraCDi x GraUDo	286.154	1	286.154	1.365	ns	.052	.203
Error(Display)	5242.119	25	209.685		ns		
TarSEsf	95.434	2	47.717	0.841	ns	.033	.186
TarSEsf x Age	109.334	2	54.667	0.963	ns	.037	.208
TarSEsf x Gender	27.885	2	13.942	0.246	ns	.010	.087
TarSEsf x Visual First	29.940	2	14.970	0.264	ns	.010	.089
TarSEsf x GraCDi	132.655	2	66.327	1.169	ns	.045	.245
TarSEsf x GraUDo	231.375	2	115.687	2.039	ns	.075	.401
TarSEsf x GraCDi x GraUDo	15.585	2	7.793	0.137	ns	.005	.070
Error(TarSEsf**)**	2837.232	50	56.745		ns		
Display x TarSEsf	178.319	2	89.159	1.790	ns	.067	.357
Display x TarSEsf x Age	234.506	2	117.253	2.354	ns	.086	.455
Display x TarSEsf x Gender	30.369	2	15.184	0.305	ns	.012	.096
Display x TarSEsf x Visual First	23.630	2	11.815	0.237	ns	.009	.085
Display x TarSEsf x GraCDi	138.828	2	69.414	1.394	ns	.053	.286
Display x TarSEsf x GraUDo	403.431	2	201.715	4.050	.023	.139	.695
Display x TarSEsf x GraCDi x GraUDo	3.593	2	1.797	0.036	ns	.001	.055
Errorw	2490.204	50	49.804				

Table 33: Means for Display x TarSEsf x GraCDi x GarUDo on WL

	Vis+Tac/TarS	Vis+Tac/TarEf	Vis+Tac/TarEs	Tac/TarS	Tac/TarEf	Tac/TarEs
GraC/GraU	24.1667	24.1667	25.5833	31.1667	37.7917	32.0000
GraC/GraDo	16.6667	20.1667	19.6250	37.1667	35.2083	42.9583
GraDi/GraU	33.0833	32.2083	33.0833	47.3750	48.4167	39.5000
GraDi/GraDo	11.9583	17.2917	16.1250	26.7500	21.7917	26.0000

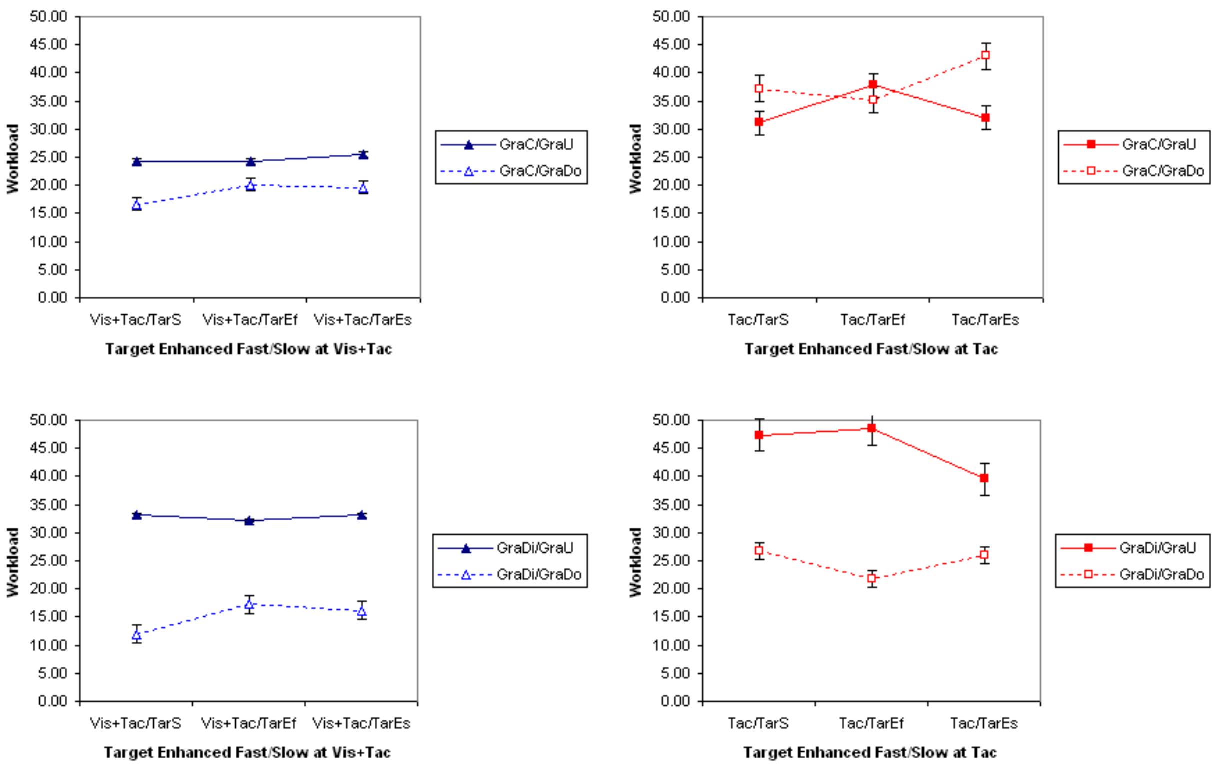
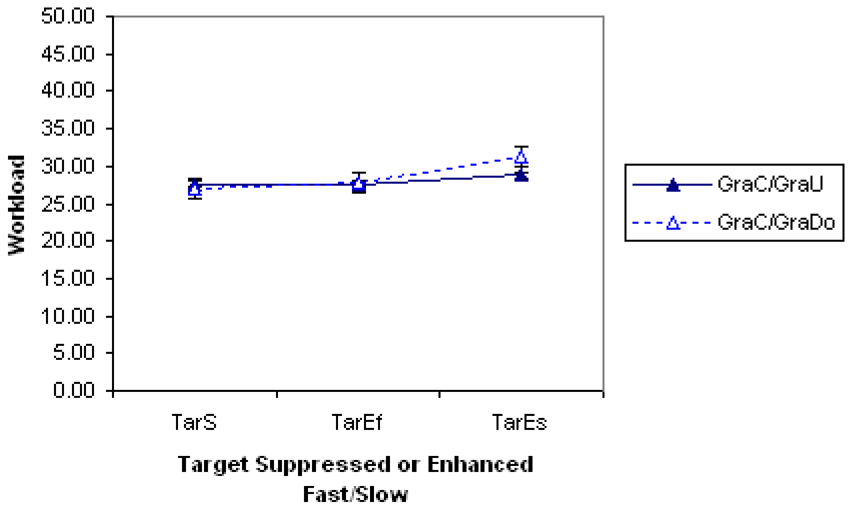


Figure 52: Display x TarSEsf x GraCDi x GarUDo on WL

Table 34: Means for TarSEsf x GraCDi x GarUDo on WL

	TarS	TarEf	TarEs
GraC/GraU	27.6667	27.6667	28.7917
GraC/GraDo	26.9167	27.6875	31.2917
GraDi/GraU	40.2292	40.3125	36.2917
GraDi/GraDo	19.3542	19.5417	21.0625



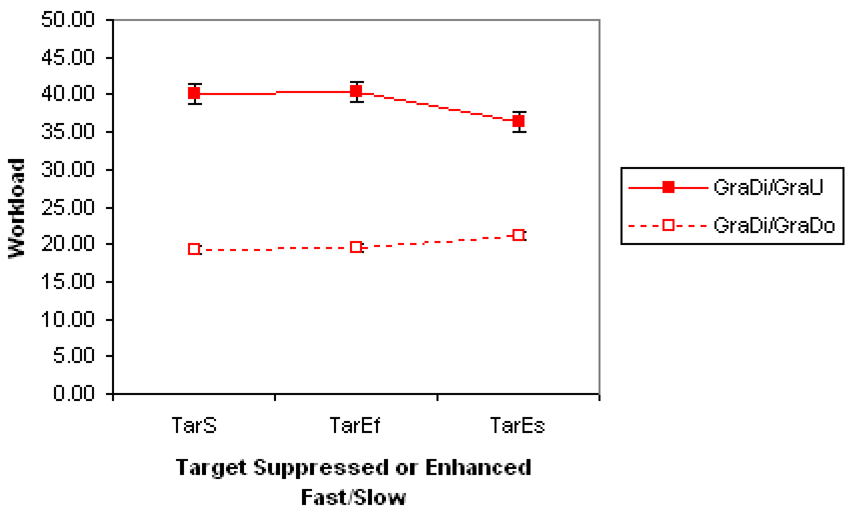


Figure 53: TarSEsf x GraCDi x GarUDo on WL

Table 35: Means for Display x TarSEsf x GraUDo on WL

	Vis+Tac/TarS	Vis+Tac/TarEf	Vis+Tac/TarEs	Tac/TarS	Tac/TarEf	Tac/TarEs
GraU	28.6250	28.1875	29.3333	39.2708	43.1042	35.7500
GraDo	14.3125	18.7292	17.8750	31.9583	28.5000	34.4792

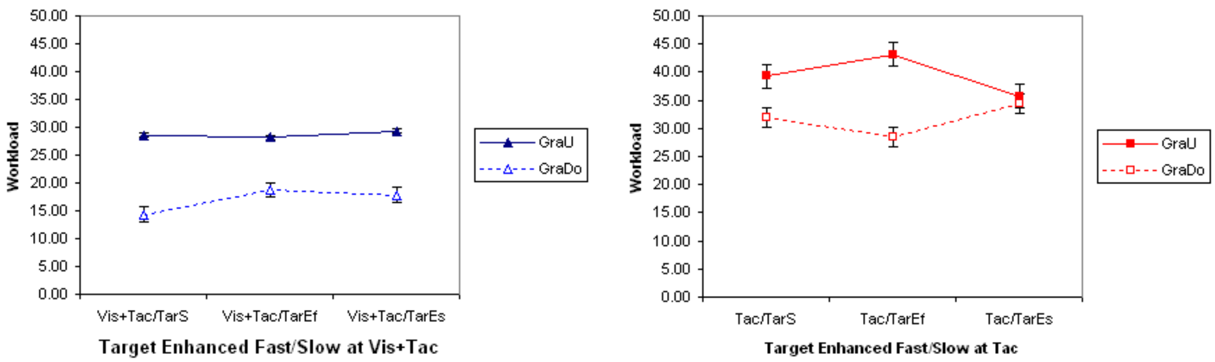


Figure 54: Display x TarSEsf x GraUDo on WL

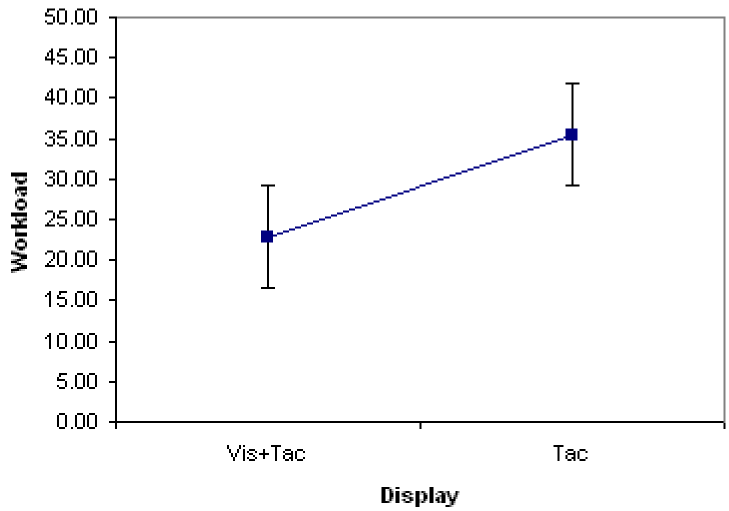


Figure 55: Display on WL

The Tactile-Only display condition resulted in more perceived workload than Visual + Tactile. No other main effects were significant.

For the Tac display condition, GraU at Tac/TarEf had higher WL than GraU at Tac/TarEs. All other pairwise comparisons involving only the Tac display condition were not significant.

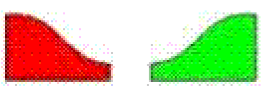
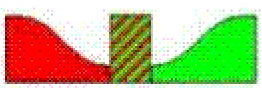
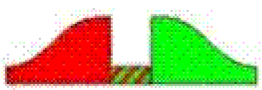
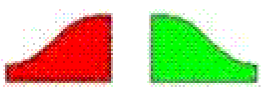
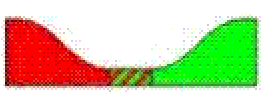
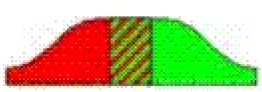
For the Vis+Tac display condition, GraU had higher WL than GraDo for all comparisons. GraDo at Vis+Tac/TarS had lower WL than GraDo at Vis+Tac/TarEf and Vis+Tac/TarEs. GraDo at Vis+Tac/TarEf and GraDo at Vis+Tac/TarEs were not significantly different.

With the exception of GraU at TarEs, GraU at Vis+Tac had lower WL than GraU at Tac for all pairwise comparisons. GraDo at Vis+Tac had lower WL for all pairwise comparisons with Tac.

Discussion

The data suggest that the larger the difference between off- and on-target cues (e.g., TarS/GraU, TarEs/GraU, TarEf/GraDo), the less time the participant spends on the target before selecting the target, and the less time it takes from target pop-up for the participant to select the target (see Table 36). This appears to be particularly true when the approach to the target is with an increasing pulse rate (GraU). These results support the hypothesis that variation in pulse rate when moving On/Off the target will result in shorter time-on-target than no variation in pulse rate.

Table 36: Rank-Order of Distance and On-Target Cues

Rank Order		Final Time On-Target (sec)	Selection Time (sec)
TarS x GraU		0.4943	2.8326
TarEs x GraU		0.6264	2.7342
TarEf x GraDo		0.5390	3.3631
TarS x GraDo		0.5960	3.6075
TarEf x GraU		0.5020	2.8486
TarEs x GraDo		0.6531	3.5692

Given that there was no difference in target selection time across the continuous and discrete conditions, the data also suggest that gradient continuity is not necessary on this measure of marksmanship. There was, however, a significant interaction of GraCDi with TarSEsf on fTot. This interaction provides support for the hypothesis that variation in pulse rate when moving On/Off the target will result in shorter time-on-target than no variation in pulse rate, since the largest differences between off- and on-target cues resulted in shorter times on target. Generally, however, the results support the hypothesis that discontinuous vibrotactile direction and distance cues will result in identical target selection times to continuous vibrotactile direction and distance cues.

Data necessary for determining velocity and acceleration profiles relative to the combinations of target size and distance from origin were collected in Experiments 1 & 2; we will be presenting these velocity and acceleration profiles in a later paper. By investigating these profiles, we can more fully understand how the interaction between GraCDi and TarSEsf affects target selection.

We did not explore the plethora of possible gradients. Instead, we chose to use the prototypical movement profile from Experiment 1 as the curve driving the vibrotactile relative distance gradient. Likewise, during the discrete gradient conditions, continuous guidance cues were provided when the participant moved away from the target irrespective of target distance.

We did not investigate the fully discrete gradient option since we were interested only in the approach phase of the target selection task, and since SME comments on the matter suggested that full-time location and relative distance cues were annoying and possibly counterproductive. Future investigations may more fully explore the ramifications of this partial-feedback approach.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The purpose of this project was to establish if vibrotactile guidance cues can improve marksmanship. To that end, this project has been successful.

Experiment 1 established the affect on initial response to vibrotactile guidance cues of tactor placements on the palm (palmer) versus on the back of the hand (dorsal), and targets appearing left versus right of center. Results suggest that tactile cues provided on the left side of the medial line of the hand afford moving the hand to the left, while tactile cues provided on the right side of the medial line afford moving the hand to the right.

Experiment 2 established the affect of continuous relative distance cues and on- versus off-target vibrotactile stimuli on reaction time and accuracy for target selection. Results suggest that there may be an interaction between the pulse rate of vibrotactile stimuli and the method used to highlight an "on-target" condition. Generally, the suppressed target condition was superior to the enhanced target condition. This was particularly true when the pulse rate increased as the cursor moved closer to a target.

Experiment 3 established if there are performance differences between discrete and continuous distance information for target selection, and investigated the interaction between the near-target pulse rate and on-target cues. Results suggest that maximizing the difference between near-target guidance cues and on-target cues reduces the target selection time, particularly when the near-target pulse rates are fast (ISI = 10 msec). The results also suggest that, as with vision, the vibrotactile off-target guidance cues are not necessary during the whole target selection task. Rather, the guidance cues can be provided only during the initial pop-up condition and during the sub-movements closing on the target with little or no change in performance.

Practical Implications

The results obtained from the studies described herein offer several practical implications for the design of vibrotactile guidance cues for target identification:

1. It is possible to reduce the visual search time by almost half.
2. Some form of relative distance cue should be provided in addition to the direction cue to reduce uncertainty regarding position relative to the target.
3. Generally, when varying the pulse rate with distance off-target, and when providing for on-target cues, the larger the difference between near- and on-target the better. The *worst* combination of cues is to have the same on-target pulse rate as the near-target pulse rate. For our project, we found the best combination of cues is to have a fast pulse rate (e.g., ISI = 10 msec) near the target, with vibrotactile cues absent on-target. The next best combination of cues is to have a fast pulse rate near the target, with slow pulse rates (e.g., ISI = 250 msec) from both tactors on-target.

Recommendations for Future Research

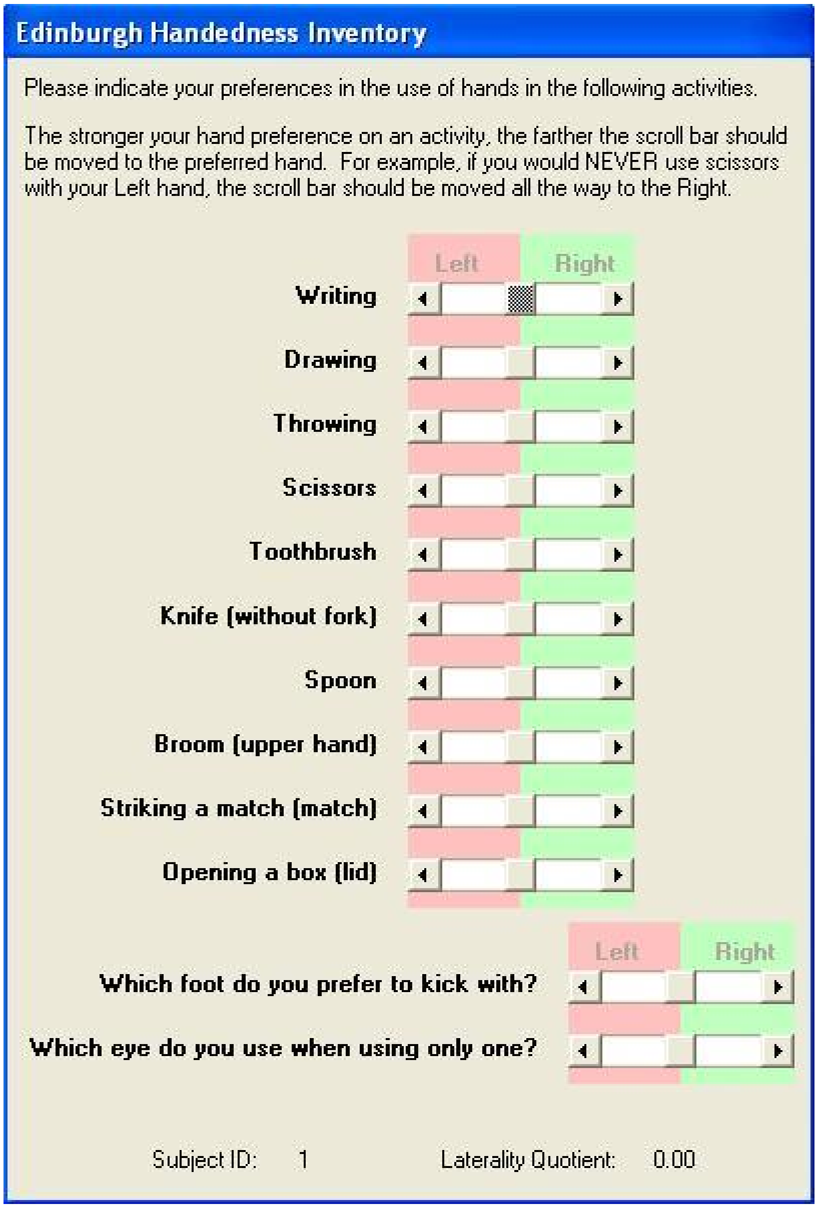
For these studies, visual target cues were set against a visual background that must be searched. Tactile target cues were set against a relatively quiet background. Future research needs to vary the background noise to fully explore the affect background has on tactile vs. visual perception of guidance cues.

These experiments do not exhaust the possible combinations of gradient continuity. Rather, the designs focus on establishing the affect of subtle versus extreme variations in on- versus off-target guidance cues, and whether or not a continuously presented gradient is necessary for providing guidance cues to the target. Subtle variations in this series of experiments were presented by simply adding or removing a tactor from a stimulus. For example, when moving from off- to on-target, a subtle variation in guidance cues would be adding a second tactor to the first at the same pulse rate and in sync with the first tactor's pulse rate, where the on-target pulse rate is the same as the near-target pulse rate. An extreme variation in guidance cues would be a fast pulse rate (ISI = 10 msec) near the target, with an absence of any vibrotactile stimulation on-target. Future research needs to explore various pulse rate gradients off-target.

Experience with the tactors seems to affect participants' ability to perform the target selection task irrespective of the type of tactile guidance cues provided. This appears to be particularly true when prior experience included both visual and tactile displays. It also appears to be true when participants take the time to explore the full range of the tactile display during training rather than simply seeking the target. For future iterations of this methodology, emphasizing the exploration of the tactile display for a target or two during training may help to reduce the number of targets required to generate a stable movement profile with little variability.

Though effective for establishing the affordance of vibrotactile guidance cues applied to the same surface of the hand oriented with the palmer surface parallel and perpendicular to the floor, this series of experiments did not fully explore the affordance of these stimuli applied to opposite surfaces (e.g., one tactor palmer and one tactor dorsal) or with more diverse hand orientations. Since the tactors would most likely be applied to only one surface of the hand in TAGS (i.e., palmer or dorsal), our purpose for these studies was to establish, among other things, which surface of the hand should be employed for our given application rather than exploring the more fundamental affordance issues requiring an exhaustive analysis of the possible combinations of tactor placement and hand orientation. Such a study would permit a more complete analysis of the possible shift between negative- and positive-feedback that may occur with multi-surface tactor placement spanning a wide range of hand orientations with respect to the floor.

APPENDIX: EHI


Edinburgh Handedness Inventory
Please indicate your preferences in the use of hands in the following activities.
The stronger your hand preference on an activity, the farther the scroll bar should be moved to the preferred hand. For example, if you would NEVER use scissors with your Left hand, the scroll bar should be moved all the way to the Right.
Left
Right
Writing
Drawing
Throwing
Scissors
Toothbrush
Knife (without fork)
Spoon
Broom (upper hand)
Striking a match (match)
Opening a box (lid)
Left
Right
Which foot do you prefer to kick with?
Which eye do you use when using only one?
Subject ID: 1
Laterality Quotient: 0.00

APPENDIX: TDB

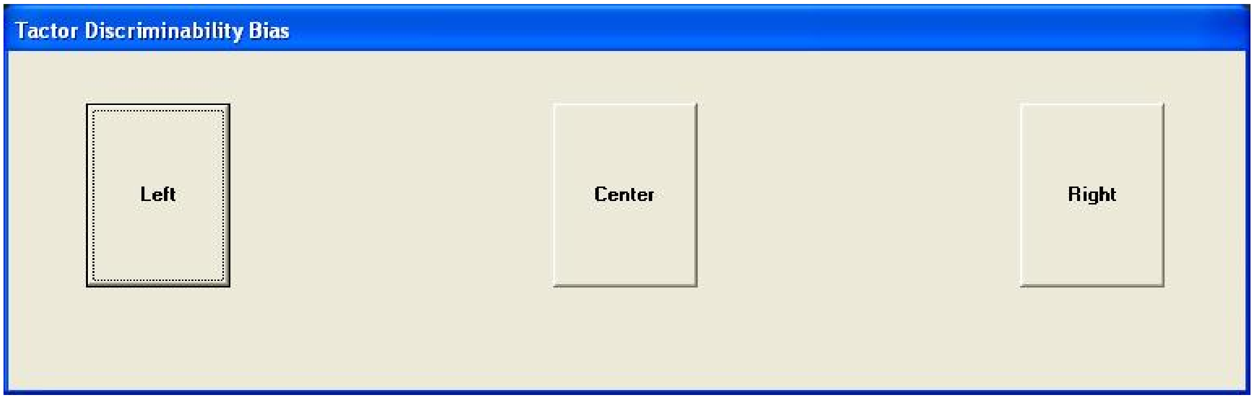


Figure 56: TDB Pulse selection task

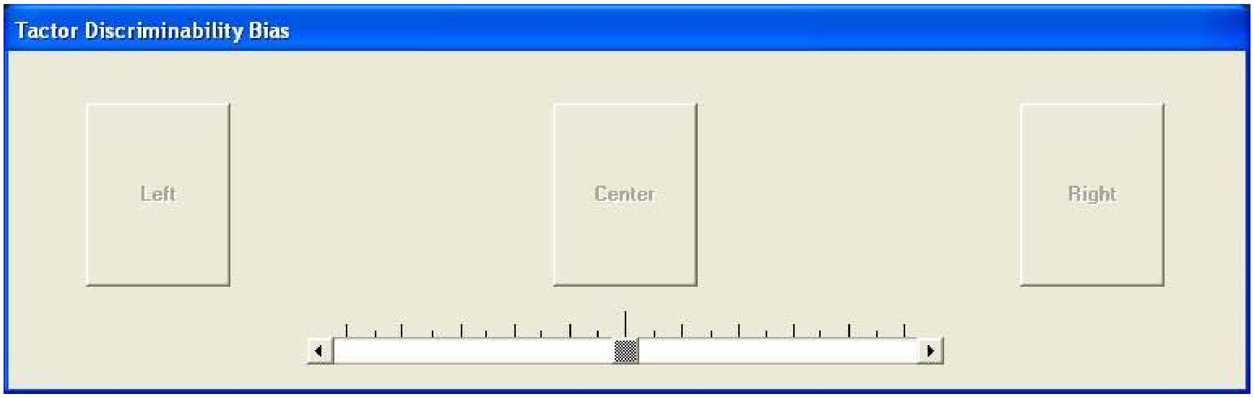


Figure 57: TDB Tactor Bias

APPENDIX: WORKLOAD DATA

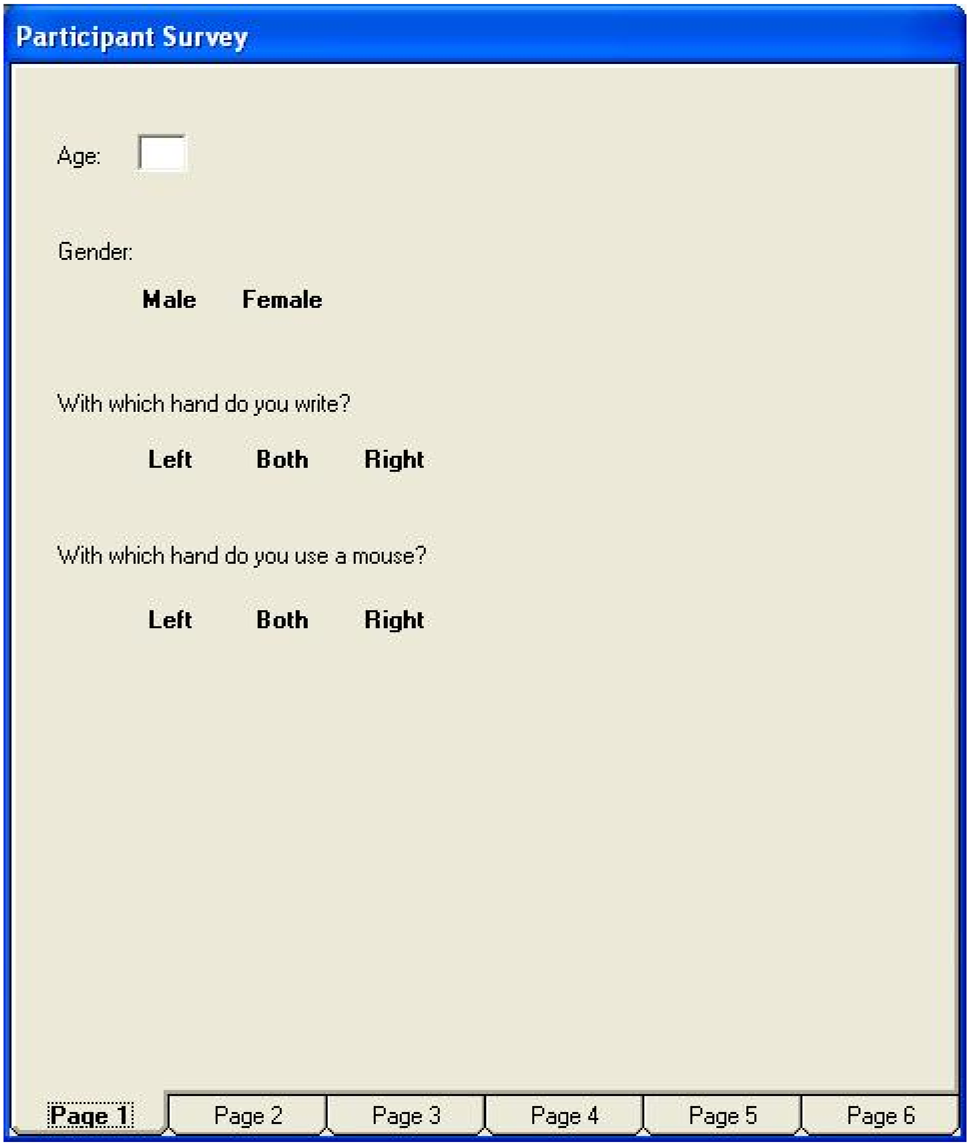
	Vis FIRST				Tac FIRST			
	GraC		GraDi		GraC		GraDi	
	GraU	GraDo	GraU	GraDo	GraU	GraDo	GraU	GraDo
Mental Demand	4.42	10.88	11.17	3.17	3.58	5.17	5.67	4.29
Physical Demand	5.92	4.21	5.08	2.17	1.79	2.50	4.04	2.21
Temporal Demand	10.21	6.33	11.83	4.42	4.13	3.67	6.46	3.46
Effort	7.96	6.96	9.25	2.92	3.58	4.29	5.21	4.17
Performance	3.88	6.00	8.08	4.25	4.79	2.63	4.29	4.42
Frustration	4.08	4.04	3.08	3.29	2.83	2.08	4.58	3.25
Mental Demand Weight	2.75	4.25	4.00	3.75	2.25	4.75	2.25	3.75
Physical Demand Weight	2.50	1.25	1.00	0.25	2.50	1.25	0.75	1.00
Temporal Demand Weight	3.00	3.25	3.00	3.75	3.25	2.50	3.50	1.25
Effort Weight	3.75	2.50	3.50	2.75	2.50	3.00	2.50	3.00
Performance Weight	1.75	2.25	2.75	2.25	3.75	1.75	3.50	4.00
Frustration Weight	1.25	1.50	0.75	2.25	0.75	1.75	2.50	2.00
WL	40.01	37.40	50.51	19.92	18.28	19.86	27.38	20.06

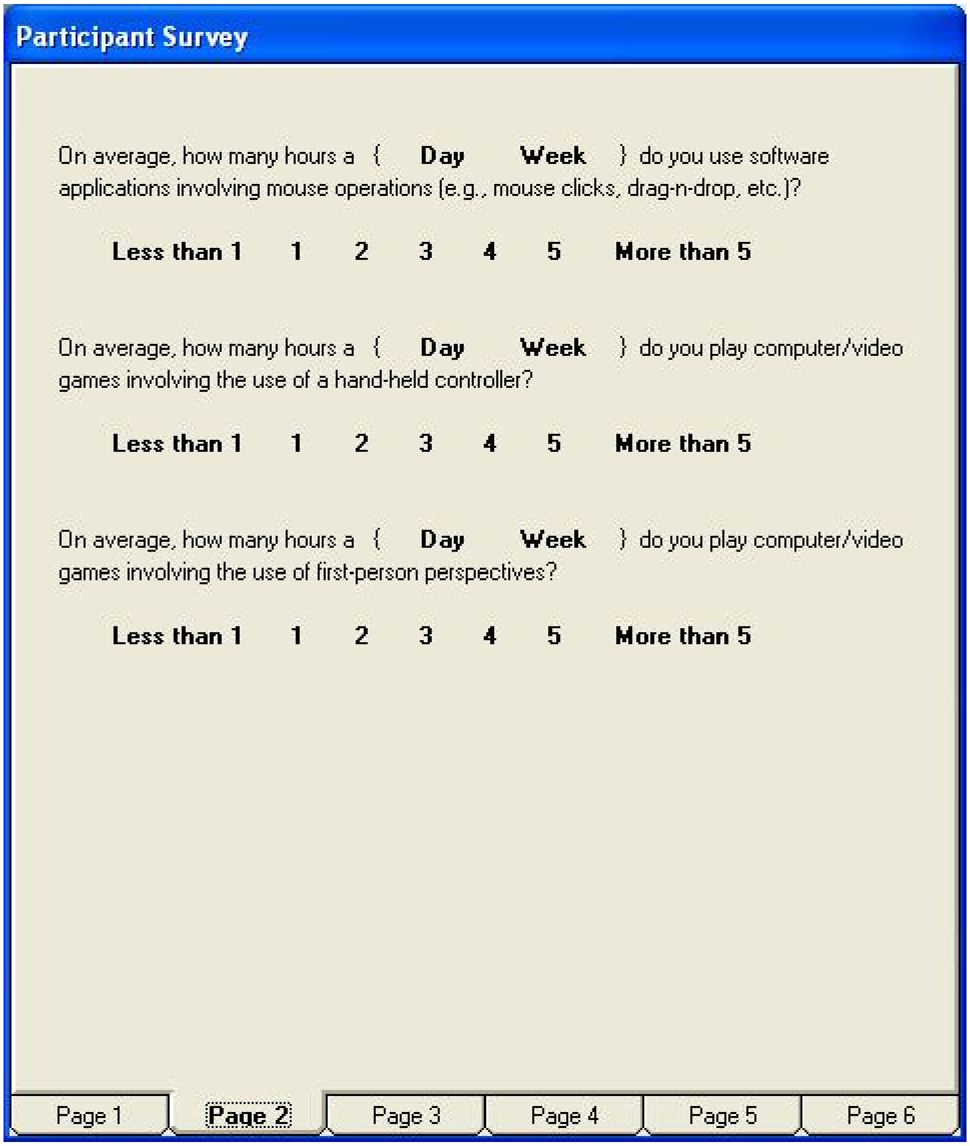
Figure 58: Workload Data, Vis+Tac First vs. Tac First

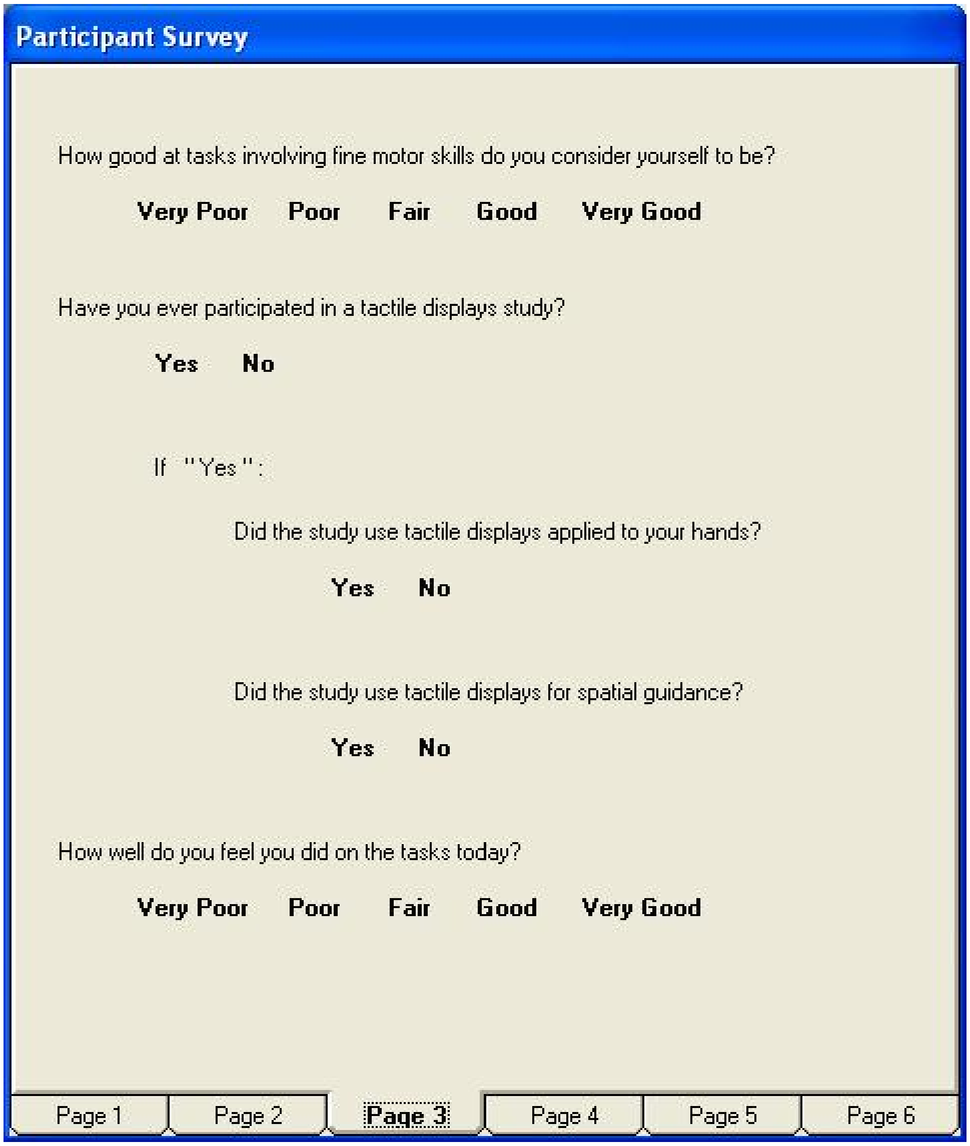
	Vis+Tac				Tac			
	GraC		GraDi		GraC		GraDi	
	GraU	GraDo	GraU	GraDo	GraU	GraDo	GraU	GraDo
Mental Demand	2.33	5.88	6.54	2.46	5.67	10.17	10.29	5.00
Physical Demand	3.67	2.13	4.92	1.88	4.04	4.58	4.21	2.50
Temporal Demand	6.67	4.13	8.96	3.58	7.67	5.88	9.33	4.29
Effort	4.54	3.33	4.79	2.29	7.00	7.92	9.67	4.79
Performance	3.50	2.79	4.75	3.63	5.17	5.83	7.63	5.04
Frustration	2.71	1.29	2.75	1.96	4.21	4.83	4.92	4.58
Mental Demand Weight	2.50	4.50	3.13	3.75	2.50	4.50	3.13	3.75
Physical Demand Weight	2.50	1.25	0.88	0.63	2.50	1.25	0.88	0.63
Temporal Demand Weight	3.13	2.88	3.25	2.50	3.13	2.88	3.25	2.50
Effort Weight	3.13	2.75	3.00	2.88	3.13	2.75	3.00	2.88
Performance Weight	2.75	2.00	3.13	3.13	2.75	2.00	3.13	3.13
Frustration Weight	1.00	1.63	1.63	2.13	1.00	1.63	1.63	2.13
WL	24.64	18.82	32.79	15.13	33.65	38.44	45.10	24.85

Figure 59: Workload Data, Vis+Tac vs. Tac

APPENDIX: SURVEY DATA


Participant Survey
Age:
Gender:
Male
Female
With which hand do you write?
Left
Both
Right
With which hand do you use a mouse?
Left
Both
Right
Page 1
Page 2
Page 3
Page 4
Page 5
Page 6


Participant Survey
On average, how many hours a { Day Week } do you use software applications involving mouse operations (e.g., mouse clicks, drag-n-drop, etc.)?
Less than 1 1 2 3 4 5 More than 5
On average, how many hours a { Day Week } do you play computer/video games involving the use of a hand-held controller?
Less than 1 1 2 3 4 5 More than 5
On average, how many hours a { Day Week } do you play computer/video games involving the use of first-person perspectives?
Less than 1 1 2 3 4 5 More than 5
Page 1
Page 2
Page 3
Page 4
Page 5
Page 6



Participant Survey

How good at tasks involving fine motor skills do you consider yourself to be?

Very Poor **Poor** **Fair** **Good** **Very Good**

Have you ever participated in a tactile displays study?

Yes **No**

If "Yes":

Did the study use tactile displays applied to your hands?

Yes **No**

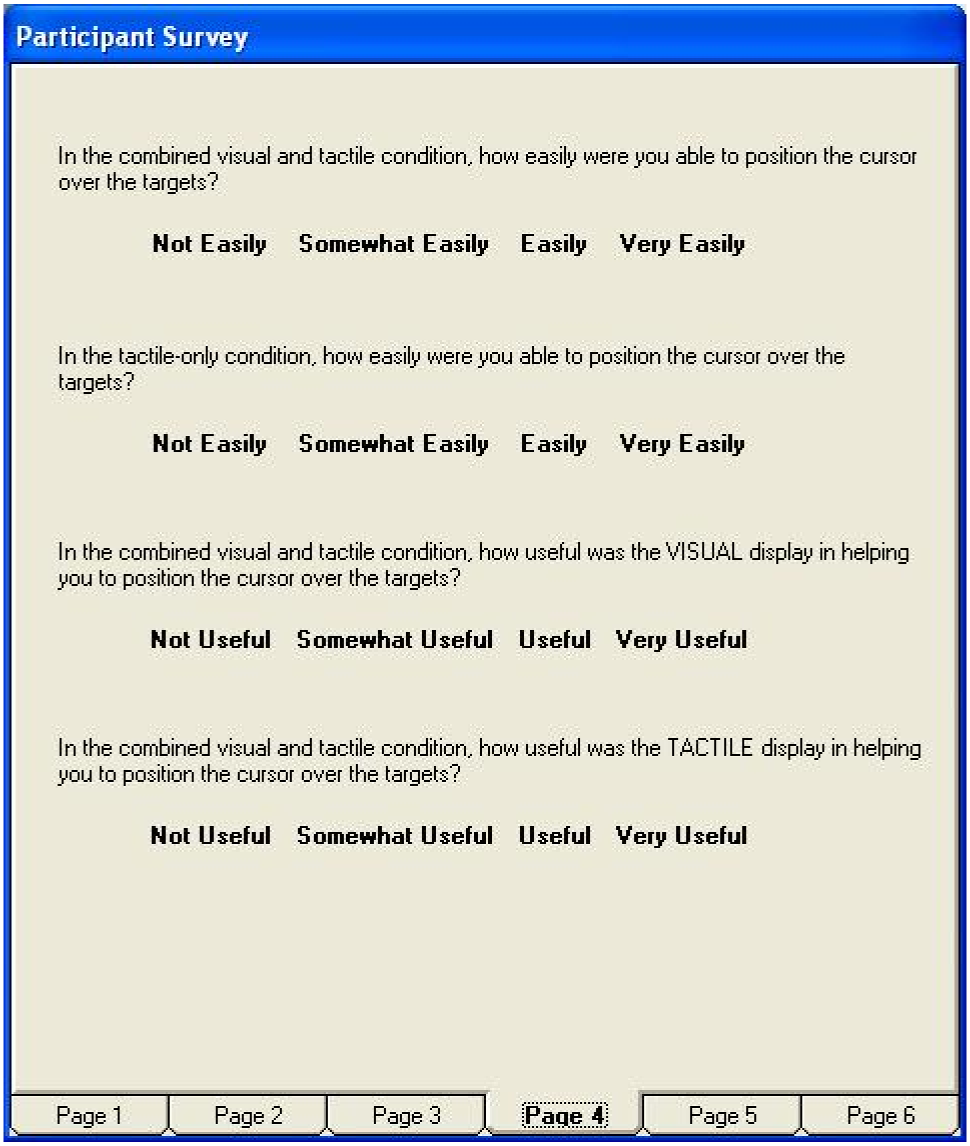
Did the study use tactile displays for spatial guidance?

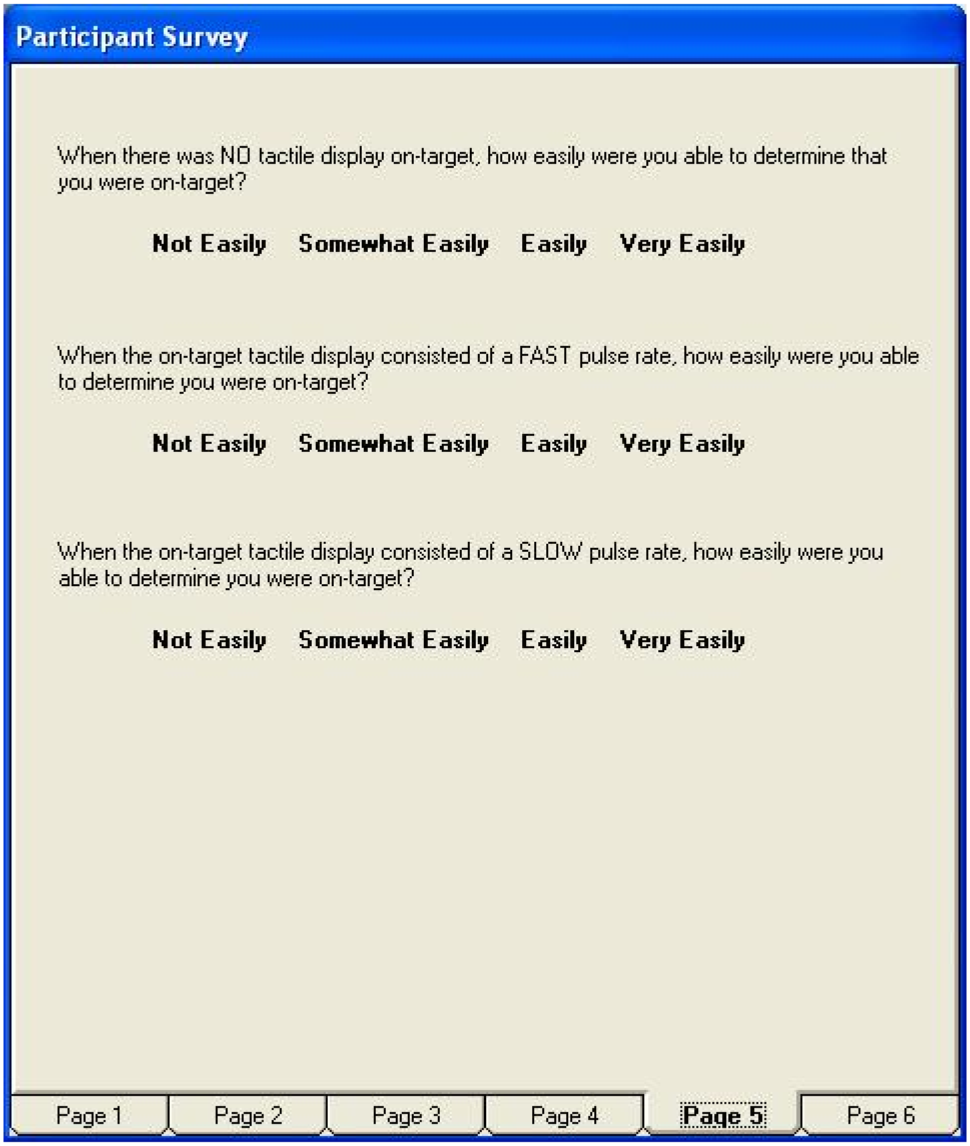
Yes **No**

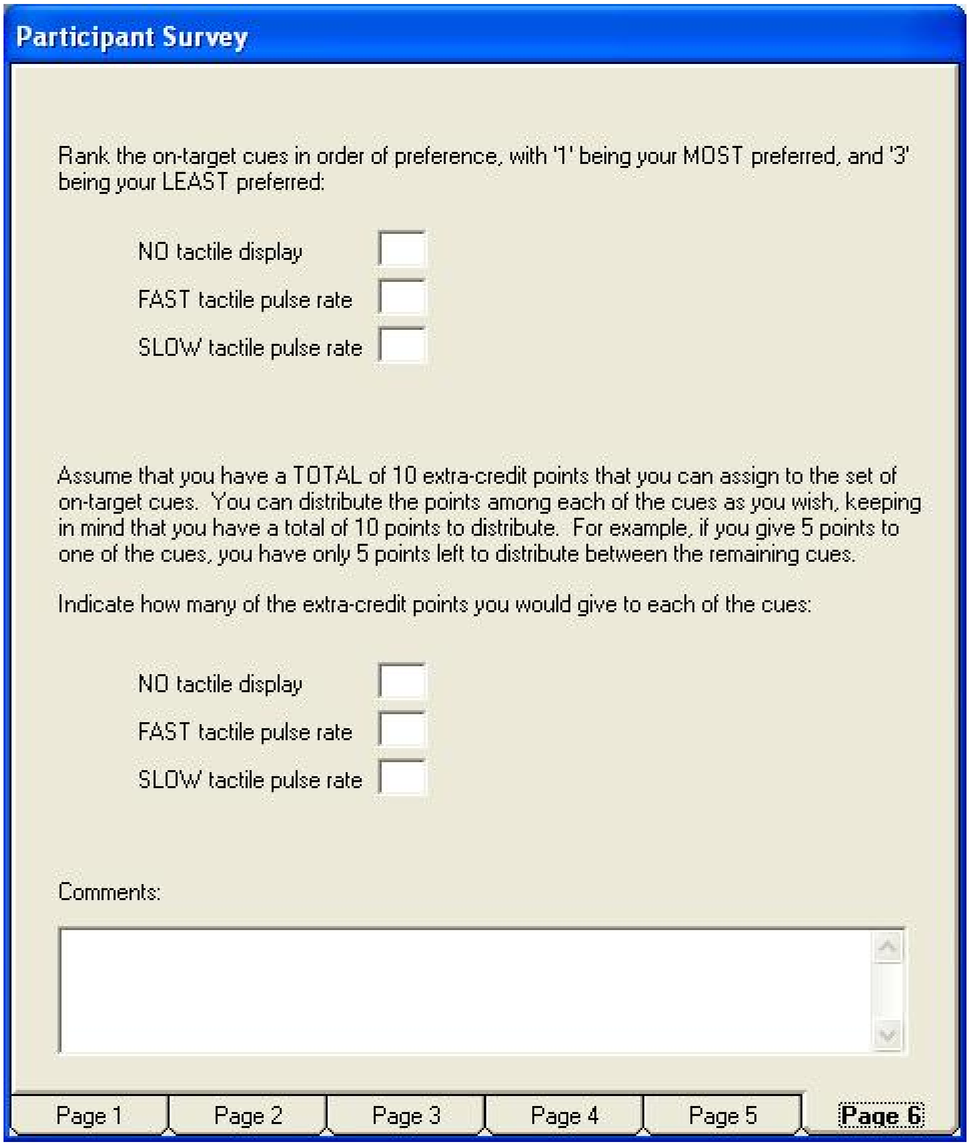
How well do you feel you did on the tasks today?

Very Poor **Poor** **Fair** **Good** **Very Good**

Page 1 | Page 2 | Page 3 | Page 4 | Page 5 | Page 6


Participant Survey
In the combined visual and tactile condition, how easily were you able to position the cursor over the targets?
Not Easily
Somewhat Easily
Easily
Very Easily
In the tactile-only condition, how easily were you able to position the cursor over the targets?
Not Easily
Somewhat Easily
Easily
Very Easily
In the combined visual and tactile condition, how useful was the VISUAL display in helping you to position the cursor over the targets?
Not Useful
Somewhat Useful
Useful
Very Useful
In the combined visual and tactile condition, how useful was the TACTILE display in helping you to position the cursor over the targets?
Not Useful
Somewhat Useful
Useful
Very Useful
Page 1
Page 2
Page 3
Page 4
Page 5
Page 6


Participant Survey
When there was NO tactile display on-target, how easily were you able to determine that you were on-target?
Not Easily Somewhat Easily Easily Very Easily
When the on-target tactile display consisted of a FAST pulse rate, how easily were you able to determine you were on-target?
Not Easily Somewhat Easily Easily Very Easily
When the on-target tactile display consisted of a SLOW pulse rate, how easily were you able to determine you were on-target?
Not Easily Somewhat Easily Easily Very Easily
Page 1
Page 2
Page 3
Page 4
Page 5
Page 6



Participant Survey

Rank the on-target cues in order of preference, with '1' being your MOST preferred, and '3' being your LEAST preferred:

NO tactile display

FAST tactile pulse rate

SLOW tactile pulse rate

Assume that you have a TOTAL of 10 extra-credit points that you can assign to the set of on-target cues. You can distribute the points among each of the cues as you wish, keeping in mind that you have a total of 10 points to distribute. For example, if you give 5 points to one of the cues, you have only 5 points left to distribute between the remaining cues.

Indicate how many of the extra-credit points you would give to each of the cues:

NO tactile display

FAST tactile pulse rate

SLOW tactile pulse rate

Comments:

Page 1 | Page 2 | Page 3 | Page 4 | Page 5 | Page 6

	VisFirst				TacFirst			
	GraC		GraDi		GraC		GraDi	
	GraU	GraDo	GraU	GraDo	GraU	GraDo	GraU	GraDo
Age	32.75	24.25	23.25	23.50	20.75	20.50	21.00	21.75
Gender (0 Female, 1 Male)	0.25	0.25	0.50	0.50	0.50	0.00	0.00	0.25
Hand Write (0 Left, 1 Right)	1.00	1.00	1.00	1.00	0.50	0.50	0.50	1.00
Hand Mouse (0 Left, 1 Right)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Span Mouse (0 Day, 1 Week)	0.00	0.00	0.00	0.25	0.25	0.00	0.25	0.00
Hours Mouse	3.75	2.75	3.25	5.00	4.50	2.75	2.50	3.75
Span Game (0 Day, 1 Week)	0.75	0.75	0.75	0.25	0.50	0.75	1.00	0.50
Hours Game	1.25	0.75	1.75	2.00	1.75	1.25	1.00	2.00
Span Perspective (0 Day, 1 Week)	1.00	0.50	0.75	0.50	0.75	1.00	1.00	0.75
Hours Perspective	0.00	0.00	0.75	1.50	1.50	0.25	0.00	1.75
Motor Skill	2.75	2.50	3.00	2.75	2.75	2.75	2.75	2.75
Tac Study Before	0.00	0.25	0.25	0.25	0.25	0.00	0.25	0.25
Tac Study Hands	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00
Tac Study Spatial	0.00	0.25	0.25	0.00	0.25	0.00	0.25	0.25
Task Today	2.75	2.50	2.75	2.50	3.00	2.75	2.25	2.75
Vis+Tac Pos	2.50	2.00	2.50	3.00	2.25	2.50	2.25	2.75
Tac Only Pos	1.00	1.00	1.00	1.25	1.25	1.50	0.50	1.25
Vis+Tac Vis Useful	2.50	2.75	3.00	2.75	3.00	3.00	2.75	2.50
Vis+Tac Tac Useful	1.75	1.75	0.75	1.25	1.50	1.75	1.00	1.75
No Tac On-Target	2.50	1.50	1.25	1.25	1.75	2.25	1.75	2.00
Tac On-Target Fast	1.25	2.50	1.25	2.25	0.75	2.75	1.25	2.75
Tac On-Target Slow	1.50	1.00	1.50	1.25	2.25	1.75	1.75	1.25
Pref No Tac On-Target	1.50	2.00	1.50	2.00	1.25	1.25	1.75	2.00
Pref Fast Tac On-Target	2.50	1.75	2.25	1.75	3.00	1.75	2.25	1.25
Pref Slow Tac On-Target	2.00	2.25	2.25	2.25	1.75	3.00	2.00	2.75
Credit No Tac On-Target	5.50	3.50	4.50	2.75	5.75	6.25	3.25	3.25
Credit Fast Tac On-Target	1.75	4.25	3.00	5.25	1.25	2.50	3.00	5.00
Credit Slow Tac On-Target	2.75	2.25	2.50	2.00	3.00	1.25	3.75	1.75

Note: All selections range from '0' to *n*

Figure 60: Survey Data, VisFirst vs. TacFirst

APPENDIX: CORRELATION TABLES

Table 37: Survey Correlations, Vis+Tac Suppressed

		Age	Gender	EHI Laterality Quotient	Mouse Use (hrs/day)	General Game Use (hrs/day)	First Person Games (hrs/day)
Age	Pearson Correlation	1	-.174	.233	.097	-.101	-.111
	Sig. (2-tailed)	.	.342	.200	.596	.583	.546
	N	32	32	32	32	32	32
Gender	Pearson Correlation	-.174	1	.063	.333	.442*	.348
	Sig. (2-tailed)	.342	.	.733	.062	.011	.051
	N	32	32	32	32	32	32
EHI Laterality Quotient	Pearson Correlation	.233	.063	1	-.078	-.059	-.026
	Sig. (2-tailed)	.200	.733	.	.673	.750	.886
	N	32	32	32	32	32	32
Mouse Use (hrs/day)	Pearson Correlation	.097	.333	-.078	1	.363*	.276
	Sig. (2-tailed)	.596	.062	.673	.	.041	.126
	N	32	32	32	32	32	32
General Game Use (hrs/day)	Pearson Correlation	-.101	.442*	-.059	.363*	1	.793**
	Sig. (2-tailed)	.583	.011	.750	.041	.	.000
	N	32	32	32	32	32	32
First Person Games (hrs/day)	Pearson Correlation	-.111	.348	-.026	.276	.793**	1
	Sig. (2-tailed)	.546	.051	.886	.126	.000	.
	N	32	32	32	32	32	32
Initial Movement Time (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.029	-.370*	.291	-.067	-.150	-.204
	Sig. (2-tailed)	.875	.037	.106	.716	.414	.264
	N	32	32	32	32	32	32
Probability of Correct Initial Movement (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.034	-.028	.150	-.091	-.106	-.257
	Sig. (2-tailed)	.855	.881	.411	.620	.564	.155
	N	32	32	32	32	32	32
First Time Move from Off- to On-Target (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.065	-.287	-.143	.131	-.152	-.154
	Sig. (2-tailed)	.722	.111	.434	.476	.407	.401
	N	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.143	-.337	-.198	.098	-.266	-.167
	Sig. (2-tailed)	.436	.059	.278	.592	.141	.360
	N	32	32	32	32	32	32
n Movements from Off- to On-Target (Vis+Tac, On-Target Suppressd)	Pearson Correlation	.045	.035	-.002	-.065	-.040	.147
	Sig. (2-tailed)	.807	.850	.991	.724	.828	.421
	N	32	32	32	32	32	32
Target Selection Time (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.097	-.495**	-.135	.080	-.139	-.082
	Sig. (2-tailed)	.597	.004	.462	.663	.447	.656
	N	32	32	32	32	32	32
n Clicks (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.173	-.068	-.060	-.110	-.198	-.136
	Sig. (2-tailed)	.344	.712	.745	.548	.277	.459
	N	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Vis+Tac, On-Target Suppressed)	Pearson Correlation	-.029	-.457**	.040	.006	.137	.098
	Sig. (2-tailed)	.875	.008	.829	.975	.455	.594
	N	32	32	32	32	32	32
Workload (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.416*	.053	-.029	-.155	-.017	-.159
	Sig. (2-tailed)	.018	.772	.875	.398	.926	.386
	N	32	32	32	32	32	32

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 38: Survey Correlations, Vis+Tac Enhanced Fast

		Age	Gender	EHI Laterality Quotient	Mouse Use (hrs/day)	General Game Use (hrs/day)	First Person Games (hrs/day)
Age	Pearson Correlation	1	-.174	.233	.097	-.101	-.111
	Sig. (2-tailed)	.	.342	.200	.596	.583	.546
	N	32	32	32	32	32	32
Gender	Pearson Correlation	-.174	1	.063	.333	.442*	.348
	Sig. (2-tailed)	.342	.	.733	.062	.011	.051
	N	32	32	32	32	32	32
EHI Laterality Quotient	Pearson Correlation	.233	.063	1	-.078	-.059	-.026
	Sig. (2-tailed)	.200	.733	.	.673	.750	.886
	N	32	32	32	32	32	32
Mouse Use (hrs/day)	Pearson Correlation	.097	.333	-.078	1	.363*	.276
	Sig. (2-tailed)	.596	.062	.673	.	.041	.126
	N	32	32	32	32	32	32
General Game Use (hrs/day)	Pearson Correlation	-.101	.442*	-.059	.363*	1	.793**
	Sig. (2-tailed)	.583	.011	.750	.041	.	.000
	N	32	32	32	32	32	32
First Person Games (hrs/day)	Pearson Correlation	-.111	.348	-.026	.276	.793**	1
	Sig. (2-tailed)	.546	.051	.886	.126	.000	.
	N	32	32	32	32	32	32
Initial Movement Time (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	-.067	-.249	.199	-.074	-.110	-.097
	Sig. (2-tailed)	.715	.169	.275	.688	.549	.599
	N	32	32	32	32	32	32
Probability of Correct Initial Movement (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.100	.214	.085	-.184	.138	.127
	Sig. (2-tailed)	.585	.240	.645	.314	.451	.489
	N	32	32	32	32	32	32
First Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.002	-.311	-.109	-.010	-.279	-.323
	Sig. (2-tailed)	.993	.083	.554	.956	.123	.072
	N	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	-.011	-.354*	.082	-.070	-.198	-.121
	Sig. (2-tailed)	.952	.047	.655	.705	.278	.511
	N	32	32	32	32	32	32
n Movements from Off- to On-Target (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	-.094	.158	.252	.067	.307	.449**
	Sig. (2-tailed)	.609	.387	.164	.715	.087	.010
	N	32	32	32	32	32	32
Target Selection Time (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.028	-.357*	.104	-.014	-.061	-.036
	Sig. (2-tailed)	.880	.045	.573	.940	.740	.843
	N	32	32	32	32	32	32
n Clicks (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	-.063	.026	-.018	-.331	-.206	-.013
	Sig. (2-tailed)	.731	.888	.921	.064	.259	.943
	N	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.072	-.198	.088	.075	.169	.105
	Sig. (2-tailed)	.693	.277	.633	.684	.354	.568
	N	32	32	32	32	32	32
Workload (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.444*	.076	.061	-.136	-.022	-.218
	Sig. (2-tailed)	.011	.678	.738	.459	.906	.230
	N	32	32	32	32	32	32

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 39: Survey Correlations, Vis+Tac Enhanced Slow

		Age	Gender	EHI Laterality Quotient	Mouse Use (hrs/day)	General Game Use (hrs/day)	First Person Games (hrs/day)
Age	Pearson Correlation	1	-.174	.233	.097	-.101	-.111
	Sig. (2-tailed)	.	.342	.200	.596	.583	.546
	N	32	32	32	32	32	32
Gender	Pearson Correlation	-.174	1	.063	.333	.442*	.348
	Sig. (2-tailed)	.342	.	.733	.062	.011	.051
	N	32	32	32	32	32	32
EHI Laterality Quotient	Pearson Correlation	.233	.063	1	-.078	-.059	-.026
	Sig. (2-tailed)	.200	.733	.	.673	.750	.886
	N	32	32	32	32	32	32
Mouse Use (hrs/day)	Pearson Correlation	.097	.333	-.078	1	.363*	.276
	Sig. (2-tailed)	.596	.062	.673	.	.041	.126
	N	32	32	32	32	32	32
General Game Use (hrs/day)	Pearson Correlation	-.101	.442*	-.059	.363*	1	.793**
	Sig. (2-tailed)	.583	.011	.750	.041	.	.000
	N	32	32	32	32	32	32
First Person Games (hrs/day)	Pearson Correlation	-.111	.348	-.026	.276	.793**	1
	Sig. (2-tailed)	.546	.051	.886	.126	.000	.
	N	32	32	32	32	32	32
Initial Movement Time (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	-.059	-.419*	.212	.050	-.180	-.137
	Sig. (2-tailed)	.750	.017	.245	.788	.323	.453
	N	32	32	32	32	32	32
Probability of Correct Initial Movement (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.058	.235	-.021	.149	.190	.051
	Sig. (2-tailed)	.754	.195	.908	.416	.298	.782
	N	32	32	32	32	32	32
First Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.231	-.512**	-.027	-.114	-.257	-.233
	Sig. (2-tailed)	.203	.003	.882	.536	.156	.199
	N	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.160	-.475**	.029	-.105	-.281	-.131
	Sig. (2-tailed)	.382	.006	.873	.567	.119	.476
	N	32	32	32	32	32	32
n Movements from Off- to On-Target (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	-.279	.186	.018	-.011	.118	.326
	Sig. (2-tailed)	.121	.308	.922	.950	.520	.068
	N	32	32	32	32	32	32
Target Selection Time (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.162	-.559**	-.026	-.033	-.214	-.067
	Sig. (2-tailed)	.376	.001	.888	.856	.240	.717
	N	32	32	32	32	32	32
n Clicks (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.061	-.161	.025	-.143	-.240	-.143
	Sig. (2-tailed)	.742	.378	.894	.436	.186	.435
	N	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.095	-.450**	-.102	.094	-.016	.063
	Sig. (2-tailed)	.604	.010	.580	.609	.931	.733
	N	32	32	32	32	32	32
Workload (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.489**	.042	-.023	-.060	-.029	-.206
	Sig. (2-tailed)	.005	.821	.900	.743	.875	.259
	N	32	32	32	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 40: Survey Correlations, Tac Suppressed

		Age	Gender	EHI Laterality Quotient	Mouse Use (hrs/day)	General Game Use (hrs/day)	First Person Games (hrs/day)
Age	Pearson Correlation	1	-.174	.233	.097	-.101	-.111
	Sig. (2-tailed)	.	.342	.200	.596	.583	.546
	N	32	32	32	32	32	32
Gender	Pearson Correlation	-.174	1	.063	.333	.442*	.348
	Sig. (2-tailed)	.342	.	.733	.062	.011	.051
	N	32	32	32	32	32	32
EHI Laterality Quotient	Pearson Correlation	.233	.063	1	-.078	-.059	-.026
	Sig. (2-tailed)	.200	.733	.	.673	.750	.886
	N	32	32	32	32	32	32
Mouse Use (hrs/day)	Pearson Correlation	.097	.333	-.078	1	.363*	.276
	Sig. (2-tailed)	.596	.062	.673	.	.041	.126
	N	32	32	32	32	32	32
General Game Use (hrs/day)	Pearson Correlation	-.101	.442*	-.059	.363*	1	.793**
	Sig. (2-tailed)	.583	.011	.750	.041	.	.000
	N	32	32	32	32	32	32
First Person Games (hrs/day)	Pearson Correlation	-.111	.348	-.026	.276	.793**	1
	Sig. (2-tailed)	.546	.051	.886	.126	.000	.
	N	32	32	32	32	32	32
Initial Movement Time (Tac, On-Target Suppressed)	Pearson Correlation	-.184	.002	.320	.206	-.059	.036
	Sig. (2-tailed)	.313	.991	.074	.259	.750	.845
	N	32	32	32	32	32	32
Probability of Correct Initial Movement (Tac, On-Target Suppressed)	Pearson Correlation	-.028	.067	.214	.115	-.077	-.157
	Sig. (2-tailed)	.879	.718	.239	.531	.676	.390
	N	32	32	32	32	32	32
First Time Move from Off- to On-Target (Tac, On-Target Suppressed)	Pearson Correlation	-.227	-.301	.077	-.087	-.224	-.131
	Sig. (2-tailed)	.212	.095	.677	.635	.219	.475
	N	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Tac, On-Target Suppressed)	Pearson Correlation	.190	-.382*	.292	-.091	-.059	.079
	Sig. (2-tailed)	.298	.031	.105	.622	.746	.669
	N	32	32	32	32	32	32
n Movements from Off- to On-Target (Tac, On-Target Suppressed)	Pearson Correlation	.488**	-.125	.248	-.053	.002	.133
	Sig. (2-tailed)	.005	.497	.171	.775	.993	.469
	N	32	32	32	32	32	32
Target Selection Time (Tac, On-Target Suppressed)	Pearson Correlation	.176	-.393*	.283	-.069	-.052	.074
	Sig. (2-tailed)	.335	.026	.117	.708	.779	.687
	N	32	32	32	32	32	32
n Clicks (Tac, On-Target Suppressed)	Pearson Correlation	.001	-.172	.111	-.199	.044	.149
	Sig. (2-tailed)	.996	.346	.544	.274	.812	.417
	N	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Tac, On-Target Suppressed)	Pearson Correlation	-.001	-.371*	.115	.146	.034	.010
	Sig. (2-tailed)	.997	.037	.531	.426	.855	.957
	N	32	32	32	32	32	32
Workload (Tac, On-Target Suppressed)	Pearson Correlation	.172	.021	.059	-.324	-.016	-.186
	Sig. (2-tailed)	.346	.911	.749	.071	.931	.307
	N	32	32	32	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 41: Survey Correlations, Tac Enhanced Fast

		Age	Gender	EHI Laterality Quotient	Mouse Use (hrs/day)	General Game Use (hrs/day)	First Person Games (hrs/day)
Age	Pearson Correlation	1	-.174	.233	.097	-.101	-.111
	Sig. (2-tailed)	.	.342	.200	.596	.583	.546
	N	32	32	32	32	32	32
Gender	Pearson Correlation	-.174	1	.063	.333	.442*	.348
	Sig. (2-tailed)	.342	.	.733	.062	.011	.051
	N	32	32	32	32	32	32
EHI Laterality Quotient	Pearson Correlation	.233	.063	1	-.078	-.059	-.026
	Sig. (2-tailed)	.200	.733	.	.673	.750	.886
	N	32	32	32	32	32	32
Mouse Use (hrs/day)	Pearson Correlation	.097	.333	-.078	1	.363*	.276
	Sig. (2-tailed)	.596	.062	.673	.	.041	.126
	N	32	32	32	32	32	32
General Game Use (hrs/day)	Pearson Correlation	-.101	.442*	-.059	.363*	1	.793**
	Sig. (2-tailed)	.583	.011	.750	.041	.	.000
	N	32	32	32	32	32	32
First Person Games (hrs/day)	Pearson Correlation	-.111	.348	-.026	.276	.793**	1
	Sig. (2-tailed)	.546	.051	.886	.126	.000	.
	N	32	32	32	32	32	32
Initial Movement Time (Tac, On-Target Enhanced Fast)	Pearson Correlation	-.014	.042	.169	.262	-.034	.044
	Sig. (2-tailed)	.941	.819	.356	.148	.853	.812
	N	32	32	32	32	32	32
Probability of Correct Initial Movement (Tac, On-Target Enhanced Fast)	Pearson Correlation	-.273	.437*	.249	.084	.186	.172
	Sig. (2-tailed)	.131	.012	.170	.648	.308	.347
	N	32	32	32	32	32	32
First Time Move from Off- to On-Target (Tac, On-Target Enhanced Fast)	Pearson Correlation	.068	-.358*	.045	-.148	-.313	-.249
	Sig. (2-tailed)	.712	.044	.808	.419	.081	.169
	N	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Tac, On-Target Enhanced Fast)	Pearson Correlation	.226	-.166	.001	.008	-.177	-.134
	Sig. (2-tailed)	.213	.365	.995	.966	.332	.464
	N	32	32	32	32	32	32
n Movements from Off- to On-Target (Tac, On-Target Enhanced Fast)	Pearson Correlation	.071	.192	.089	.109	.070	.131
	Sig. (2-tailed)	.699	.291	.629	.551	.702	.475
	N	32	32	32	32	32	32
Target Selection Time (Tac, On-Target Enhanced Fast)	Pearson Correlation	.241	-.197	.008	.018	-.193	-.143
	Sig. (2-tailed)	.183	.279	.967	.920	.291	.434
	N	32	32	32	32	32	32
n Clicks (Tac, On-Target Enhanced Fast)	Pearson Correlation	.309	-.019	.091	-.078	-.077	-.114
	Sig. (2-tailed)	.086	.918	.621	.671	.674	.536
	N	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Tac, On-Target Enhanced Fast)	Pearson Correlation	.169	-.285	.052	.086	-.160	-.100
	Sig. (2-tailed)	.356	.114	.778	.640	.382	.587
	N	32	32	32	32	32	32
Workload (Tac, On-Target Enhanced Fast)	Pearson Correlation	.376*	-.069	-.027	-.237	-.026	-.230
	Sig. (2-tailed)	.034	.706	.885	.192	.888	.206
	N	32	32	32	32	32	32

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 42: Survey Correlations, Tac Enhanced Slow

		Age	Gender	EHI Laterality Quotient	Mouse Use (hrs/day)	General Game Use (hrs/day)	First Person Games (hrs/day)
Age	Pearson Correlation	1	-.174	.233	.097	-.101	-.111
	Sig. (2-tailed)	.	.342	.200	.596	.583	.546
	N	32	32	32	32	32	32
Gender	Pearson Correlation	-.174	1	.063	.333	.442*	.348
	Sig. (2-tailed)	.342	.	.733	.062	.011	.051
	N	32	32	32	32	32	32
EHI Laterality Quotient	Pearson Correlation	.233	.063	1	-.078	-.059	-.026
	Sig. (2-tailed)	.200	.733	.	.673	.750	.886
	N	32	32	32	32	32	32
Mouse Use (hrs/day)	Pearson Correlation	.097	.333	-.078	1	.363*	.276
	Sig. (2-tailed)	.596	.062	.673	.	.041	.126
	N	32	32	32	32	32	32
General Game Use (hrs/day)	Pearson Correlation	-.101	.442*	-.059	.363*	1	.793**
	Sig. (2-tailed)	.583	.011	.750	.041	.	.000
	N	32	32	32	32	32	32
First Person Games (hrs/day)	Pearson Correlation	-.111	.348	-.026	.276	.793**	1
	Sig. (2-tailed)	.546	.051	.886	.126	.000	.
	N	32	32	32	32	32	32
Initial Movement Time (Tac, On-Target Enhanced Slow)	Pearson Correlation	-.107	.084	.141	.137	.068	.298
	Sig. (2-tailed)	.561	.649	.443	.456	.710	.098
	N	32	32	32	32	32	32
Probability of Correct Initial Movement (Tac, On-Target Enhanced Slow)	Pearson Correlation	.114	.277	.069	-.215	-.054	-.106
	Sig. (2-tailed)	.533	.125	.706	.237	.771	.562
	N	32	32	32	32	32	32
First Time Move from Off- to On-Target (Tac, On-Target Enhanced Slow)	Pearson Correlation	-.179	-.374*	-.031	.019	-.281	-.227
	Sig. (2-tailed)	.326	.035	.866	.916	.119	.211
	N	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Tac, On-Target Enhanced Slow)	Pearson Correlation	-.086	-.519**	.216	-.178	-.203	-.090
	Sig. (2-tailed)	.639	.002	.235	.330	.265	.625
	N	32	32	32	32	32	32
n Movements from Off- to On-Target (Tac, On-Target Enhanced Slow)	Pearson Correlation	.182	-.158	.257	-.212	.070	.183
	Sig. (2-tailed)	.319	.386	.155	.243	.705	.316
	N	32	32	32	32	32	32
Target Selection Time (Tac, On-Target Enhanced Slow)	Pearson Correlation	-.071	-.521**	.225	-.134	-.178	-.085
	Sig. (2-tailed)	.699	.002	.215	.464	.330	.644
	N	32	32	32	32	32	32
n Clicks (Tac, On-Target Enhanced Slow)	Pearson Correlation	.034	-.021	.037	-.147	-.074	.054
	Sig. (2-tailed)	.853	.911	.843	.421	.686	.769
	N	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Tac, On-Target Enhanced Slow)	Pearson Correlation	.024	-.367*	.198	.119	.000	-.036
	Sig. (2-tailed)	.896	.039	.278	.517	.999	.846
	N	32	32	32	32	32	32
Workload (Tac, On-Target Enhanced Fast)	Pearson Correlation	.125	.039	.093	-.200	-.059	-.240
	Sig. (2-tailed)	.494	.834	.614	.273	.748	.187
	N	32	32	32	32	32	32

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 43: Dependent Variable Inter Item Correlations, Vis+Tac Suppressed

		Initial Movement Time (Vis+Tac, On-Target Suppressed)	Probability of Correct Initial Movement (Vis+Tac, On-Target Suppressed)	First Time Move from Off- to On-Target (Vis+Tac, On-Target Suppressed)	Final Time Move from Off- to On-Target (Vis+Tac, On-Target Suppressed)	n Movements from Off- to On-Target (Vis+Tac, On-Target Suppressd)	Target Selection Time (Vis+Tac, On-Target Suppressed)	n Clicks (Vis+Tac, On-Target Suppressed)	Final Time Spent On-Target Before Click (Vis+Tac, On-Target Suppressed)	Workload (Vis+Tac, On-Target Suppressed)
Initial Movement Time (Vis+Tac, On-Target Suppressed)	Pearson Correlation	1	.187	.516**	.457**	-.326	.479**	-.138	.240	.045
	Sig. (2-tailed)	.	.306	.002	.009	.069	.006	.452	.185	.808
	N	32	32	32	32	32	32	32	32	32
Probability of Correct Initial Movement (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.187	1	-.276	-.284	.028	-.363*	.048	-.278	.018
	Sig. (2-tailed)	.306	.	.126	.115	.878	.041	.793	.123	.922
	N	32	32	32	32	32	32	32	32	32
First Time Move from Off- to On-Target (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.516**	-.276	1	.872**	-.612**	.824**	-.083	.280	-.051
	Sig. (2-tailed)	.002	.126	.	.000	.000	.000	.650	.121	.780
	N	32	32	32	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.457**	-.284	.872**	1	-.192	.868**	.186	.166	-.038
	Sig. (2-tailed)	.009	.115	.000	.	.291	.000	.309	.363	.837
	N	32	32	32	32	32	32	32	32	32
n Movements from Off- to On-Target (Vis+Tac, On-Target Suppressd)	Pearson Correlation	-.326	.028	-.612**	-.192	1	-.246	.373*	-.189	.041
	Sig. (2-tailed)	.069	.878	.000	.291	.	.174	.035	.300	.824
	N	32	32	32	32	32	32	32	32	32
Target Selection Time (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.479**	-.363*	.824**	.868**	-.246	1	-.108	.635**	-.057
	Sig. (2-tailed)	.006	.041	.000	.000	.174	.	.557	.000	.756
	N	32	32	32	32	32	32	32	32	32
n Clicks (Vis+Tac, On-Target Suppressed)	Pearson Correlation	-.138	.048	-.083	.186	.373*	-.108	1	-.502**	-.174
	Sig. (2-tailed)	.452	.793	.650	.309	.035	.557	.	.003	.340
	N	32	32	32	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.240	-.278	.280	.166	-.189	.635**	-.502**	1	-.054
	Sig. (2-tailed)	.185	.123	.121	.363	.300	.000	.003	.	.767
	N	32	32	32	32	32	32	32	32	32
Workload (Vis+Tac, On-Target Suppressed)	Pearson Correlation	.045	.018	-.051	-.038	.041	-.057	-.174	-.054	1
	Sig. (2-tailed)	.808	.922	.780	.837	.824	.756	.340	.767	.
	N	32	32	32	32	32	32	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 44: Dependent Variable Inter Item Correlations, Vis+Tac Enhanced Fast

		Initial Movement Time (Vis+Tac, On-Target Enhanced Fast)	Probability of Correct Initial Movement (Vis+Tac, On-Target Enhanced Fast)	First Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Fast)	Final Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Fast)	n Movements from Off- to On-Target (Vis+Tac, On-Target Enhanced Fast)	Target Selection Time (Vis+Tac, On-Target Enhanced Fast)	n Clicks (Vis+Tac, On-Target Enhanced Fast)	Final Time Spent On-Target Before Click (Vis+Tac, On-Target Enhanced Fast)	Workload (Vis+Tac, On-Target Enhanced Fast)
Initial Movement Time (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	1	.162	.537**	.560**	-.085	.486**	-.212	.153	.123
	Sig. (2-tailed)	.	.376	.002	.001	.642	.005	.243	.403	.502
	N	32	32	32	32	32	32	32	32	32
Probability of Correct Initial Movement (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.162	1	-.308	-.433*	-.027	-.341	-.177	-.048	.125
	Sig. (2-tailed)	.376	.	.086	.013	.884	.056	.331	.794	.497
	N	32	32	32	32	32	32	32	32	32
First Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.537**	-.308	1	.811**	-.540**	.717**	-.133	.250	.133
	Sig. (2-tailed)	.002	.086	.	.000	.001	000	.468	.168	.467
	N	32	32	32	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.560**	-.433*	.811**	1	-.011	.882**	.007	.303	.149
	Sig. (2-tailed)	.001	.013	.000	.	.952	.000	.969	.092	.414
	N	32	32	32	32	32	32	32	32	32
n Movements from Off- to On-Target (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	-.085	-.027	-.540**	-.011	1	-.010	.225	-.005	-.132
	Sig. (2-tailed)	.642	.884	.001	.952	.	.955	.216	.980	.473
	N	32	32	32	32	32	32	32	32	32
Target Selection Time (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.486**	-.341	.717**	.882**	-.010	1	-.259	.716**	.167
	Sig. (2-tailed)	.005	.056	.000	.000	.955	.	.153	.000	.360
	N	32	32	32	32	32	32	32	32	32
n Clicks (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	-.212	-.177	-.133	.007	.225	-.259	1	-.534**	-.079
	Sig. (2-tailed)	.243	.331	.468	.969	.216	.153	.	.002	.668
	N	32	32	32	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.153	-.048	.250	.303	-.005	.716**	-.534**	1	.117
	Sig. (2-tailed)	.403	.794	.168	.092	.980	.000	.002	.	.524
	N	32	32	32	32	32	32	32	32	32
Workload (Vis+Tac, On-Target Enhanced Fast)	Pearson Correlation	.123	.125	.133	.149	-.132	.167	-.079	.117	1
	Sig. (2-tailed)	.502	.497	.467	.414	.473	.360	.668	.524	.
	N	32	32	32	32	32	32	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 45: Dependent Variable Inter Item Correlations, Vis+Tac Enhanced Slow

		Initial Movement Time (Vis+Tac, On-Target Enhanced Slow)	Probability of Correct Initial Movement (Vis+Tac, On-Target Enhanced Slow)	First Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Slow)	Final Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Slow)	n Movements from Off- to On-Target (Vis+Tac, On-Target Enhanced Slow)	Target Selection Time (Vis+Tac, On-Target Enhanced Slow)	n Clicks (Vis+Tac, On-Target Enhanced Slow)	Final Time Spent On-Target Before Click (Vis+Tac, On-Target Enhanced Slow)	Workload (Vis+Tac, On-Target Enhanced Slow)
Initial Movement Time (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	1	.109	.590**	.443*	-.428*	.520**	-.172	.418*	-.213
	Sig. (2-tailed)	.	.552	.000	.011	.015	.002	.348	.017	.242
	N	32	32	32	32	32	32	32	32	32
Probability of Correct Initial Movement (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.109	1	-.143	-.315	-.381*	-.291	.180	-.128	.206
	Sig. (2-tailed)	.552	.	.436	.079	.031	.106	.323	.485	.259
	N	32	32	32	32	32	32	32	32	32
First Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.590**	-.143	1	.877**	-.499**	.819**	-.060	.375*	.109
	Sig. (2-tailed)	.000	.436	.	.000	.004	.000	.744	.034	.554
	N	32	32	32	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.443*	-.315	.877**	1	-.051	.899**	.150	.352*	-.019
	Sig. (2-tailed)	.011	.079	.000	.	.780	.000	.414	.048	.920
	N	32	32	32	32	32	32	32	32	32
n Movements from Off- to On-Target (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	-.428*	-.381*	-.499**	-.051	1	-.114	.317	-.163	-.281
	Sig. (2-tailed)	.015	.031	.004	.780	.	.535	.077	.373	.120
	N	32	32	32	32	32	32	32	32	32
Target Selection Time (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.520**	-.291	.819**	.899**	-.114	1	-.091	.726**	-.012
	Sig. (2-tailed)	.002	.106	.000	.000	.535	.	.621	.000	.947
	N	32	32	32	32	32	32	32	32	32
n Clicks (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	-.172	.180	-.060	.150	.317	-.091	1	-.430*	-.028
	Sig. (2-tailed)	.348	.323	.744	.414	.077	.621	.	.014	.879
	N	32	32	32	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	.418*	-.128	.375*	.352*	-.163	.726**	-.430*	1	.003
	Sig. (2-tailed)	.017	.485	.034	.048	.373	.000	.014	.	.988
	N	32	32	32	32	32	32	32	32	32
Workload (Vis+Tac, On-Target Enhanced Slow)	Pearson Correlation	-.213	.206	.109	-.019	-.281	-.012	-.028	.003	1
	Sig. (2-tailed)	.242	.259	.554	.920	.120	.947	.879	.988	.
	N	32	32	32	32	32	32	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 46: Dependent Variable Inter Item Correlations, Tac Suppressed

		Initial Movement Time (Tac, On-Target Suppressed)	Probability of Correct Initial Movement (Tac, On-Target Suppressed)	First Time Move from Off- to On-Target (Tac, On-Target Suppressed)	Final Time Move from Off- to On-Target (Tac, On-Target Suppressed)	n Movements from Off- to On-Target (Tac, On-Target Suppressed)	Target Selection Time (Tac, On-Target Suppressed)	n Clicks (Tac, On-Target Suppressed)	Final Time Spent On-Target Before Click (Tac, On-Target Suppressed)	Workload (Tac, On-Target Suppressed)
Initial Movement Time (Tac, On-Target Suppressed)	Pearson Correlation	1	.713**	.341	-.126	-.338	-.113	-.332	.041	-.248
	Sig. (2-tailed)	.	.000	.056	.491	.059	.538	.063	.824	.171
	N	32	32	32	32	32	32	32	32	32
Probability of Correct Initial Movement (Tac, On-Target Suppressed)	Pearson Correlation	.713**	1	-.063	-.297	-.199	-.289	-.325	-.125	-.060
	Sig. (2-tailed)	.000	.	.733	.098	.274	.109	.070	.496	.746
	N	32	32	32	32	32	32	32	32	32
First Time Move from Off- to On-Target (Tac, On-Target Suppressed)	Pearson Correlation	.341	-.063	1	.334	-.416*	.337	.048	.255	-.219
	Sig. (2-tailed)	.056	.733	.	.061	.018	.059	.793	.158	.229
	N	32	32	32	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Tac, On-Target Suppressed)	Pearson Correlation	-.126	-.297	.334	1	.651**	.997**	.690**	.664**	.126
	Sig. (2-tailed)	.491	.098	.061	.	.000	.000	.000	.000	.493
	N	32	32	32	32	32	32	32	32	32
n Movements from Off- to On-Target (Tac, On-Target Suppressed)	Pearson Correlation	-.338	-.199	-.416*	.651**	1	.637**	.512**	.317	.199
	Sig. (2-tailed)	.059	.274	.018	.000	.	.000	.003	.077	.275
	N	32	32	32	32	32	32	32	32	32
Target Selection Time (Tac, On-Target Suppressed)	Pearson Correlation	-.113	-.289	.337	.997**	.637**	1	.672**	.720**	.127
	Sig. (2-tailed)	.538	.109	.059	.000	.000	.	.000	.000	.488
	N	32	32	32	32	32	32	32	32	32
n Clicks (Tac, On-Target Suppressed)	Pearson Correlation	-.332	-.325	.048	.690**	.512**	.672**	1	.299	.108
	Sig. (2-tailed)	.063	.070	.793	.000	.003	.000	.	.096	.556
	N	32	32	32	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Tac, On-Target Suppressed)	Pearson Correlation	.041	-.125	.255	.664**	.317	.720**	.299	1	.103
	Sig. (2-tailed)	.824	.496	.158	.000	.077	.000	.096	.	.576
	N	32	32	32	32	32	32	32	32	32
Workload (Tac, On-Target Suppressed)	Pearson Correlation	-.248	-.060	-.219	.126	.199	.127	.108	.103	1
	Sig. (2-tailed)	.171	.746	.229	.493	.275	.488	.556	.576	.
	N	32	32	32	32	32	32	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 47: Dependent Variable Inter Item Correlations, Tac Enhanced Fast

		Initial Movement Time (Tac, On-Target Enhanced Fast)	Probability of Correct Initial Movement (Tac, On-Target Enhanced Fast)	First Time Move from Off- to On-Target (Tac, On-Target Enhanced Fast)	Final Time Move from Off- to On-Target (Tac, On-Target Enhanced Fast)	n Movements from Off- to On-Target (Tac, On-Target Enhanced Fast)	Target Selection Time (Tac, On-Target Enhanced Fast)	n Clicks (Tac, On-Target Enhanced Fast)	Final Time Spent On-Target Before Click (Tac, On-Target Enhanced Fast)	Workload (Tac, On-Target Enhanced Fast)
Initial Movement Time (Tac, On-Target Enhanced Fast)	Pearson Correlation	1	.522**	.299	-.001	-.221	.038	.017	.310	-.060
	Sig. (2-tailed)	.	.002	.096	.994	.225	.836	.926	.084	.743
	N	32	32	32	32	32	32	32	32	32
Probability of Correct Initial Movement (Tac, On-Target Enhanced Fast)	Pearson Correlation	.522**	1	-.272	-.355*	-.026	-.348	-.212	-.021	-.239
	Sig. (2-tailed)	.002	.	.131	.046	.890	.051	.244	.908	.188
	N	32	32	32	32	32	32	32	32	32
First Time Move from Off- to On-Target (Tac, On-Target Enhanced Fast)	Pearson Correlation	.299	-.272	1	.601**	-.333	.595**	.481**	.079	-.033
	Sig. (2-tailed)	.096	.131	.	.000	.063	.000	.005	.669	.856
	N	32	32	32	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Tac, On-Target Enhanced Fast)	Pearson Correlation	-.001	-.355*	.601**	1	.421*	.992**	.785**	.154	.079
	Sig. (2-tailed)	.994	.046	.000	.	.016	.000	.000	.402	.669
	N	32	32	32	32	32	32	32	32	32
n Movements from Off- to On-Target (Tac, On-Target Enhanced Fast)	Pearson Correlation	-.221	-.026	-.333	.421*	1	.399*	.377*	-.082	-.063
	Sig. (2-tailed)	.225	.890	.063	.016	.	.024	.034	.656	.731
	N	32	32	32	32	32	32	32	32	32
Target Selection Time (Tac, On-Target Enhanced Fast)	Pearson Correlation	.038	-.348	.595**	.992**	.399*	1	.731**	.276	.086
	Sig. (2-tailed)	.836	.051	.000	.000	.024	.	.000	.126	.642
	N	32	32	32	32	32	32	32	32	32
n Clicks (Tac, On-Target Enhanced Fast)	Pearson Correlation	.017	-.212	.481**	.785**	.377*	.731**	1	-.258	.211
	Sig. (2-tailed)	.926	.244	.005	.000	.034	.000	.	.154	.247
	N	32	32	32	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Tac, On-Target Enhanced Fast)	Pearson Correlation	.310	-.021	.079	.154	-.082	.276	-.258	1	.071
	Sig. (2-tailed)	.084	.908	.669	.402	.656	.126	.154	.	.697
	N	32	32	32	32	32	32	32	32	32
Workload (Tac, On-Target Enhanced Fast)	Pearson Correlation	-.060	-.239	-.033	.079	-.063	.086	.211	.071	1
	Sig. (2-tailed)	.743	.188	.856	.669	.731	.642	.247	.697	.
	N	32	32	32	32	32	32	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 48: Dependent Variable Inter Item Correlations, Tac Enhanced Slow

		Initial Movement Time (Tac, On-Target Enhanced Slow)	Probability of Correct Initial Movement (Tac, On-Target Enhanced Slow)	First Time Move from Off- to On-Target (Tac, On-Target Enhanced Slow)	Final Time Move from Off- to On-Target (Tac, On-Target Enhanced Slow)	n Movements from Off- to On-Target (Tac, On-Target Enhanced Slow)	Target Selection Time (Tac, On-Target Enhanced Slow)	n Clicks (Tac, On-Target Enhanced Slow)	Final Time Spent On-Target Before Click (Tac, On-Target Enhanced Slow)	Workload (Tac, On-Target Enhanced Fast)
Initial Movement Time (Tac, On-Target Enhanced Slow)	Pearson Correlation	1	.295	.262	-.061	-.179	-.044	-.214	.052	-.018
	Sig. (2-tailed)	.	.101	.148	.739	.326	.810	.240	.779	.923
	N	32	32	32	32	32	32	32	32	32
Probability of Correct Initial Movement (Tac, On-Target Enhanced Slow)	Pearson Correlation	.295	1	-.330	-.425*	-.082	-.404*	-.051	-.174	.104
	Sig. (2-tailed)	.101	.	.065	.015	.656	.022	.780	.340	.572
	N	32	32	32	32	32	32	32	32	32
First Time Move from Off- to On-Target (Tac, On-Target Enhanced Slow)	Pearson Correlation	.262	-.330	1	.336	-.410*	.353*	-.244	.321	-.098
	Sig. (2-tailed)	.148	.065	.	.060	.020	.048	.179	.073	.592
	N	32	32	32	32	32	32	32	32	32
Final Time Move from Off- to On-Target (Tac, On-Target Enhanced Slow)	Pearson Correlation	-.061	-.425*	.336	1	.580**	.990**	.291	.629**	.249
	Sig. (2-tailed)	.739	.015	.060	.	.001	.000	.106	.000	.170
	N	32	32	32	32	32	32	32	32	32
n Movements from Off- to On-Target (Tac, On-Target Enhanced Slow)	Pearson Correlation	-.179	-.082	-.410*	.580**	1	.543**	.324	.195	.262
	Sig. (2-tailed)	.326	.656	.020	.001	.	.001	.071	.286	.147
	N	32	32	32	32	32	32	32	32	32
Target Selection Time (Tac, On-Target Enhanced Slow)	Pearson Correlation	-.044	-.404*	.353*	.990**	.543**	1	.217	.733**	.266
	Sig. (2-tailed)	.810	.022	.048	.000	.001	.	.234	.000	.142
	N	32	32	32	32	32	32	32	32	32
n Clicks (Tac, On-Target Enhanced Slow)	Pearson Correlation	-.214	-.051	-.244	.291	.324	.217	1	-.213	-.047
	Sig. (2-tailed)	.240	.780	.179	.106	.071	.234	.	.242	.797
	N	32	32	32	32	32	32	32	32	32
Final Time Spent On-Target Before Click (Tac, On-Target Enhanced Slow)	Pearson Correlation	.052	-.174	.321	.629**	.195	.733**	-.213	1	.263
	Sig. (2-tailed)	.779	.340	.073	.000	.286	.000	.242	.	.145
	N	32	32	32	32	32	32	32	32	32
Workload (Tac, On-Target Enhanced Fast)	Pearson Correlation	-.018	.104	-.098	.249	.262	.266	-.047	.263	1
	Sig. (2-tailed)	.923	.572	.592	.170	.147	.142	.797	.145	.
	N	32	32	32	32	32	32	32	32	32

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

APPENDIX: IRB HUMAN SUBJECTS PERMISSION LETTER

University of Central Florida

Office of Research and Commercialization

April 9, 2004

Richard Gilson, Ph.D.
Department of Psychology
University of Central Florida
PH, Room 302F
4000 Central Florida Boulevard
Orlando, Florida 32816-1390

Dear Dr. Gilson:

With reference to your protocol entitled, "Covert Multi-sensory Feedback for the Dismounted Soldier," I am enclosing for your records the approved, executed document of the UCFIRB Form you had submitted to our office.

Please be advised that this approval is given for one year. Should there be any addendums or administrative changes to the already approved protocol, they must also be submitted to the Board. Changes should not be initiated until written IRB approval is received. Adverse events should be reported to the IRB as they occur. Further, should there be a need to extend this protocol, a renewal form must be submitted for approval at least one month prior to the anniversary date of the most recent approval and is the responsibility of the investigator (UCF).

Should you have any questions, please do not hesitate to call me at 823-2901.

Please accept our best wishes for the success of your endeavors.

Cordially,

Chris Grayson

Chris Grayson
Institutional Review Board (IRB)

Copies: IRB File

12443 Research Parkway • Suite 302 • Orlando, FL 32826-3252 • 407-823-3778 • Fax 407-823-3299

LIST OF REFERENCES

Akamatsu, M., & MacKenzie, I.S. (1996). "Movement characteristics using a mouse with tactile and force feedback." International Journal of Human-Computer Studies, 45, 483-493.

Akamatsu, M., & Sato, S. (1994). "A multi-modal mouse with tactile and force feedback." International Journal of Human-Computer Studies, 40, 443-453.

Carlton, L.G. (1981). "Processing visual feedback information for movement control." Journal of Experimental Psychology: Human Perception and Performance, 7, 1019-1030.

Drake, C., & Botte, M. (1993). "Tempo sensitivity in auditory sequences: Eveidence for a multiple-look model." Perception & Psychophysics, 54(3), 277-286.

Fitts, P.M. (1954). "The information capacity of the human motor system in controlling amplitude of movement." Journal of Experimental Psychology, 47, 381-391.

Fitts, P.M., & Peterson, J.R. (1964). "Information capacity of discrete motor responses." Journal of Experimental Psychology, 67, 103-112.

Fitts, P.M., & Radford, B. (1966). "Information capacity of discrete motor responses under different cognitive sets." Journal of Experimental Psychology, 71, 475-482.

Friberg, A., & Sundberg, J. (1995). "Time discrimination in a monotonic, isochronous sequence." Journal of the Acoustical Society of America, 98(5, Pt 1), 2524-2431.

Henry, F.M., & Rogers, D.E. (1960). "Increased response latency for complicated movements and a 'memory drum' theory of neuromotor reaction." Research Quarterly, 31, 448-458.

Hill, J.W. (1970). "A describing function analysis of tracking performance using two tactile displays." IEEE Transactions on Man-Machine Systems, MMS-11, 92-101.

Jagacinski, R.J., Flach, J.M., & Gilson, R.D. (1983). "A comparison of visual and kinesthetic-tactual displays for compensatory tracking." IEEE Transactions on Systems, Man, and Cybernetics, SMC-13(6), 1103-1983.

Jagacinski, R.J., Miller, D.P., & Gilson, R.D. (1979). "A comparison of kinesthetic-tactual and visual displays via a critical tracking task." Human Factors, 21(1), 79-86.

Jagacinski, R.J., Pepperger, D.W., Moran, M.S., Ward, S.L., & Glass, B. (1980). "Fitts' Law and the microstructure of rapid discrete movements." Journal of Experimental Psychology: Human Perception and Performance, 6, 309-320.

Jeannerod, M., & Prablanc, C. (1983). "Visual control of reaching movements in man." In J.E. Desmedt (Ed.) Motor Control Mechanisms in Health and Disease. New York, NY: Raven Press, p. 13-29

Minsky, M., Ming, O., Steele, O., Brooks, F.P., & Behensky, M. (1990). "Feeling and seeing: Issues in force display." Computer Graphics, 24, 235-243.

Mowbray, G., & Gebhard, J. (1955). "Differential sensitivity of the eye to intermittent white light." Science, 121, 173-175.

Oldfield, R.C. (1971). "The assessment of handedness: The Edinburgh Inventory." Neuropsychologia, 9, 97-113.

Orban, G., Van Calenbergh, F., de Bruyn, B., & Maes, H. (1985). "Velocity discrimination in central and peripheral visual field." Journal of the Optical Society of America, A, Optics, Image & Science, 2(11), 1836-1847.

Priplata, A., Niemi, J., Salen, M., Harry, J., Lipsitz, L.A., & Collins, J.J. (2002). "Noise-enhanced human balance control." Physical Review Letters, 89(23).

Schmidt, R.A. (1975). "A schema theory of discrete motor skill learning." Psychological Review, 82, 225-260.

Schmidt, R. A., Zelaznik, H. N., Hawkins, B., Frank, J. S., & Quinn, J. T. (1979). "Motor-output variability: A theory for the accuracy of rapid motor acts." Psychological Review, 86(5), 415-451.

Stevens, S. (1959). "Tactile vibration: Dynamics of sensory intensity." Journal of Experimental Psychology, 57, 210-218.

Verrillo, R. (1962). "Investigation of some parameters of the cutaneous threshold for vibration." Journal of the Acoustical Society of America, 34, 1768-1773.

Verrillo, R., Fraioli, A., & Smith, R. (1969). "Sensation magnitude of vibrotactile stimuli." Perception and Psychophysics, 6(6-A), 366-372.

Wickens, C.D. (2002). "Multiple resources and performance prediction." Theoretical Issues in Ergonomics Science, 3(2), 159-177.